Library of the
University of California.

From
Edward Irving.

HOW TO KNOW THE STARRY HEAVENS

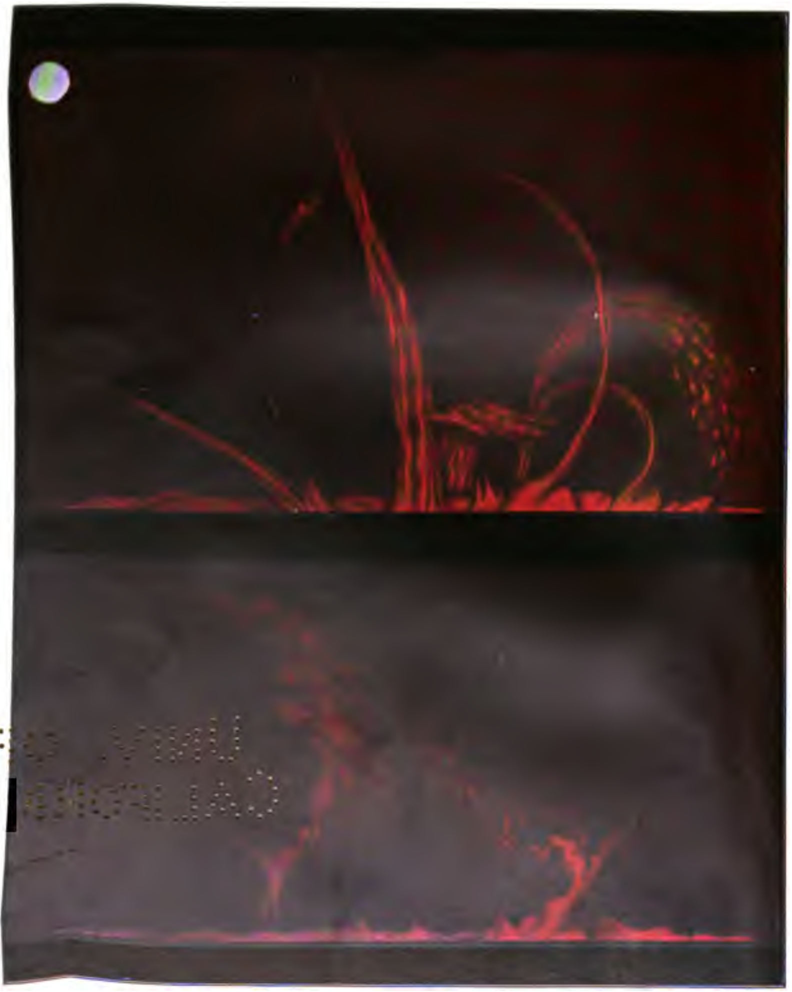


Fig. 1. — Solar Prominences, by Trouvelot, of Harvard Observatory

The white circle represents the size of the Earth on the same scale.

HOW TO KNOW

THE

STARRY HEAVENS

AN INVITATION TO THE

STUDY OF SUNS AND WORLDS

BY

EDWARD IRVING

WITH CHARTS, COLOURED PLATES, DIAGRAMS,
AND MANY ENGRAVINGS OF
PHOTOGRAPHS

NEW YORK
FREDERICK A. STOKES COMPANY
PUBLISHERS

Published in November, 1904

THE UNIVERSITY PRESS, CAMBRIDGE, U. S. A.

1530 Shattuck Av.
Berkeley Cal.
Feb 22/05

Mr J C Rowell
Dear Sir:

In reply to yours received the other day I have not a copy of "How to Know the Starry Heavens" to

984
I

DEDICATED

TO ALL TRUE CITIZENS OF THE GREAT COSMOS

AND

TO ALL WHO WISH TO BECOME SUCH

"*Everybody should study astronomy. It is the most delightful of all the sciences. It is the most inspiring of all. It lifts and broadens the mind. It rouses the imagination, and the imagination is the most God-like of human faculties, because it is the most creative. Let no one be deterred by the superstition that it is necessary to be a mathematician in order to understand and enjoy astronomy. You can let the mathematics of the subject severely alone and yet find inexhaustible pleasure and advantage in astronomical study. It is because they were compelled to begin at the mathematical end of the subject that hundreds of thousands of graduates from schools and colleges have virtually no knowledge of astronomy. Mathematical gifts are rare, but they are not essential to the enjoyment of astronomy.*" — GARRETT P. SERVISS.

PREFACE

THIS volume is not so much a text-book on Astronomy, as *an invitation to read text-books* on that subject. In other words, it is a careful selection of the most typical, interesting, and instructive facts and theories concerning the Universe around us. The author has endeavoured to describe and illustrate these in such a way as to attract, interest, and inform the general reader. But, though intended primarily for beginners, every effort has been made to avoid offending those who are further advanced, by sensationalism or a want of proportion and accuracy. The comparisons and illustrations used are the result of many years' study, and have been successfully used in lectures and classes. They may interest some who are well acquainted with the facts of astronomy, but have not looked at them from the same standpoint.

Many interesting and important astronomical methods, principles, and facts have been left out of this volume, to avoid overcrowding and confusion. The main object of the work is not so much to describe individual worlds, as to enable the reader to realise, as far as possible, what the Universe itself is like. In other words, it is to give a bird's-eye view of the celestial forest from a general and philosophical standpoint, so that the individual trees may be afterwards examined more at leisure. Until such a bird's-eye view has been obtained, the learner is apt to be confused by the details. As the old saying has it, he "cannot see the wood for the trees."

When such a general view has once been obtained, the details no longer confuse, and text-books that were formerly thrown down in disgust become luminous with the ever-growing interest that rightly belongs to the physical sciences.

The figures given in this work are mostly round numbers. They do not claim absolute accuracy, but at the same time every effort has been made to avoid serious errors.

The distance of the nearest star has been given as about 9,000 times as great as that of Neptune. It is quite possible that further investigations may result in other figures being adopted. But even if it should be changed to 8,000 or 10,000, the comparisons used will still serve to illustrate the relative dimensions of the visible Universe.

The author gratefully acknowledges the kindness of Professor R. G. Aitken and other members of the staff at the Lick Observatory, in reading the manuscript and making suggestions which have materially helped to perfect the work.

Thanks are due to many who have given advice, suggestions, corrections, and information; also to those who have granted the reproduction of valuable photographs and drawings. Among these are:

The late Dr. E. Keeler, Director of Lick Observatory, California.

Dr. W. W. Campbell, Director of Lick Observatory, California.

Dr. A. O. Leuschner, Director of Students' Observatory, Berkeley, Cal.

E. L. Larkin, Director of Lowe Observatory, California.

C. Burckhalter, Director of Chabot Observatory, Oakland, Cal.

G. E. Hale, Director of Yerkes Observatory, Wisconsin.

E. C. Pickering, Director of Harvard Observatory, Massachusetts.

W. H. M. Christie, M.A., Astronomer Royal, Greenwich, England.

E. Walter Maunder, F.R.A.S., Greenwich, England.

Besides giving an account of well-known and indisputable astronomical facts, the author has touched upon certain speculative theories which cannot yet be proved by either experiment or observation. The most that can be said for them is that they give a reasonable explanation of a large number of observed phenomena, and must therefore contain a certain amount

of truth. They also help to give us a better idea of the *Infinite and Eternal Drama* in which our little Earth is playing its obscure and ephemeral part. The reader is not asked to accept these theories if he can explain the observed phenomena by more probable speculations of his own. But he must beware of adopting theories which conflict largely with ascertained facts.

It only remains to be said that these speculations have everywhere been carefully distinguished from those facts which are so well proved as to be practically indisputable.

This volume is intended to be the first of a series, by the same writer, dealing with the sciences of astronomy, geology, biology, and sociology. These four were grouped together by the late Herbert Spencer under the name of the Concrete Sciences. Though the vast importance of these subjects is now generally recognised, many otherwise educated people are lamentably deficient in them. This is very unfortunate for the individuals concerned, for, however learned a man may be in all other subjects, it is impossible for him to be truly broad-minded, philosophical, and cosmopolitan, without some knowledge of these Concrete Sciences.[1]

A general lack of scientific knowledge injures, not only the individuals themselves, but also society at large. In spite of the great advances made in all directions during the last century, there are still many imperfections remaining in our systems of government, of administrative justice, of national education, and in our entire social and moral organisations. These imperfections are largely due to the fact that many of our statesmen, lawyers, teachers, doctors, and preachers are deficient in the above-mentioned sciences. Let us hope that during the present

[1] As the philosophical A. Zazel truly says:

"Astronomy, geology, biology, and sociology together form an impregnable bulwark against the inroads of superstition. And where the seeds of that deadly mental disease have been already sown, these sciences form an infallible antidote and cure."

century this ignorance may be removed, so that our upward progress may no longer be impeded by the erroneous ideas that have been dragged up with us from the flat world in which our ancestors imagined themselves to be living.

The second volume will deal with the history of the Third Planet in our System, from its nebulous birth to the advent of Man. Its title will probably be *How to Know the Earth's History*.

EDWARD IRVING.

BERKELEY, CAL. (U. S.),
October, 1904.

CONTENTS

Chapter		Page
I.	Apparent Motions of the Heavenly Bodies as Shown by Observation	1
II.	Rival Theories to Explain the Apparent Motions of the Heavenly Bodies	15
III.	Principles Utilised for Measuring the Universe	26
IV.	Some Problems Used in Celestial Measurements	39
V.	The Chariot of Imagination	53
VI.	Dimensions of the Universe	68
VII.	Some More Dimensions	77
VIII.	The Principles and Applications of the Spectroscope	87
IX.	A Star-Spangled Banner	102
X.	Construction of the Universe	114
XI.	Solar Architecture	125
XII.	A Reeling World	136
XIII.	Kepler's Three Laws	155
XIV.	Galileo's Laws of Motion	163
XV.	Newton's Law of Gravitation	167
XVI.	Ancient Cosmogonies, and the Nebular Hypothesis	178
XVII.	Theories and Discoveries Modifying the Nebular Hypothesis	190
XVIII.	Modifications of the Nebular Theory	205
XIX.	The Messengers of Heaven	219
XX.	Large and Small Worlds	233

CONTENTS

Chapter		Page
XXI.	Igneous Forces on the Moon and Elsewhere	243
XXII.	Lunar Geology and Geography	257
XXIII.	Inhabited Worlds	265
XXIV.	Size, Importance, Speed, and Duration	283
XXV.	Conclusion	290

Appendix A. — Facts and Fancies Concerning Matter . . 295

Appendix B. — The Greek Alphabet 301

Appendix C. — The Lunar Craters 302

Index 309

ILLUSTRATIONS

FULL-PAGE ILLUSTRATIONS

FIGURE

1. Solar Prominences, by Trouvelot, of Harvard Observatory *Frontispiece in colours*

FACING PAGE

7. Northern Star-Trails 14
8. The Dipper, or Great Bear, at Intervals of Six Hours . . . 14
24. Sun, Showing Spots and Faculæ 52
25. Group of Sunspots 58
26. Solar Flames and Corona, as Seen During Eclipse of May 28, 1900. (*In colours*) 56
27. Eruptive Prominences 58
28. Solar Corona. Eclipse of May 28, 1900 60
29. North Polar Streamers of the Corona. May 28, 1900 . . . 60
30. Mercury, the First Planet 62
31. Venus, the Second Planet 62
33. Mars, the Fourth Planet 62
35. The Zone of Asteroids Between Mars and Jupiter 64
36. Jupiter, the Largest Planet 64
38. Saturn, the Ringed Planet 66
41. Lick Observatory on Mount Hamilton, California 70
42. Main Entrance and Great Dome, Lick Observatory 70
43. The Thirty-Six-Inch Refractor at Lick Observatory 72
44. Eye-Piece of the Great Lick Telescope 74
45. Yerkes Observatory, Williams Bay, Wisconsin 80
46. The Forty-Inch Refractor of the Yerkes Observatory: the Largest in the World 80
47. Milky Way Surrounding Messier II. 84
48. The Star-Cluster Messier II. 84
53. Laboratory and Celestial Spectra. (*In colours*) 94
54. Tele-Spectroscope 96
55. The Mills Spectrograph at Lick Observatory 96
56. Chief Lines in the Solar Spectrum (Herschel) 98
57. Part of the Spectra of Four Red Stars (Hale and Ellerman) . 100
58. Star Spectra Showing Displacement of Lines Due to Star's Motion in Line of Sight 98

FIGURE FACING PAGE
59. Coloured Double Stars. (*In colours*) 108
60. Star-Cluster in Hercules 112
61. Part of the Milky Way in Sagittarius 114
62. A Rope-like Nebula in Cygnus 114
63. Spiral Nebula in Triangulum 116
64. The Great Nebula in Andromeda 118
65. A Spiral Nebula Seen Edgeways 120
66. The Ring Nebula in Lyra 120
67. The Trifid Nebula in Sagittarius 122
68. Great Nebula in Orion 124
69. A Typical Sunspot 128
70. Solar "Flames" or Prominences 132
75. The Solar Corona During the Eclipse of July 29, 1878 . . . 134
76. Theoretical Section of Solar Photosphere 132
79. Equatorial Mounting of the Crossley Reflector, Lick Observatory 150
80. Meridian Circle 150
82. Drawing an Ellipse 158
84. Mount Lowe Observatory, in Southern California 168
85. Spiral Nebula in Ursa Major (M 81) 172
91. Dumb-Bell Nebula 192
92. Nova Persei, 1901. Showing Movement of Surrounding Nebulosity. Lick Photographs 196
93. Spectra of Nova Persei, Showing Changes 200
94. The Star-Cluster Omega Centauri 204
100. A Celestial Messenger Approaching a Star 222
101. Brook's Comet, 1893 222
102. Comet 1903 C. 222
106. Donati's Comet, 1858 228
107. Comet Rordame, 1893 228
109. The California Meteor of July 27, 1894 232
113. Full Moon, Showing Radiating Streaks 244
114. The Moon, at First and Last Quarter 248
117. Clavius and Tycho 252
118. Theophilus, a Lunar Crater-With-Cone 254
122. Mare Crisium, a Lunar Plain 258
123. Lunar Apennines and Alps 258
124. Copernicus 260
125. Schickard and Wargentin 262
126. Ptolemy, Alphons, and Arzachel 264
127. Twelve Views of Mars 268
128. Disc of the Sun, August 12, 1903 274

CHARTS

	FACING PAGE
Chart A. The Northern Heavens Key to Chart A. (*In colours*)	282
Chart B. The Equatorial Constellations. For Spring Evenings Key to Chart B. (*In colours*)	290
Chart C. The Equatorial Constellations. For Summer Evenings Key to Chart C. (*In colours*)	294
Chart D. The Equatorial Constellations. For Winter Evenings Key to Chart D. (*In colours*)	300
Chart E. Eastern Half of Moon. (*In colours*) Chart F. Western Half of Moon. (*In colours*)	304
Chart G. The Constellation Figures	308

ILLUSTRATIONS IN THE TEXT

FIGURE		PAGE
2.	Umbrella-Apparatus for Illustrating (Apparent) Star Movements	5
3.	The Earth, Showing Relative Positions of Apparatus when Used at Equator, Poles, etc.	7
4.	Umbrella-Apparatus Modified for Illustrating Apparent Movements of Sun and Planets	8
5.	Circles of the Celestial Sphere with World in the Centre	9
6.	An Adjustable Equatorial, Suitable for any Part of the World	13
9.	The Ptolemaic System	19
10.	The Tychonic System	20
11.	Copernican System	23
12.	Relative Positions of Earth and Sun at the four Seasons	24
13.	Orbits of Mercury, Venus, and Earth	28
14.	Estimating Distances with the Eyes	31
15.	Surveying from a Base-line	32
16.	Daily Positions of Earth and Moon	37
17.	Arc of Circle	40
18.	Chord of Arc	41
19.	Sine of Angle	42
20.	Measuring Width of River	43
21.	Measuring Distance of Moon	46
22.	Arc of Circle	47
23.	Sine of Angle	50
32.	Terra, the Third Planet, and Its Satellite or Moon	63
34.	Relative Sizes of Earth and Mars	64
37.	Relative Sizes of Jupiter and Earth	65

FIGURE PAGE
39. Relative Sizes of Saturn and Earth 66
40. Relative Sizes of Neptune and Earth 67
49. A Prism and its Spectrum 90
50. A One-prism Spectroscope 91
51. Section of a One-prism Spectroscope 92
52. A Compound Spectroscope 93
71. A Solar "Cloud" of Glowing Hydrogen (Professor Young) . . 131
72. The Same Region 35 Minutes Later (Young) 132
73. The Same Region 35 Minutes Later (Young) 133
74. The Same, 15 Minutes Later (Young) 133
77. Diagram Illustrating Zodiac 137
78. Diagram Illustrating Precession of Equinoxes and Advance of Perihelion 143
81. Alt-Azimuth Mounting for Small Telescope 153
83. An Elliptical Orbit, Divided into Twelve Monthly Parts . . . 159
86. Original Nebula, after its Rotation has Produced a Disc-like Form 184
87. Nebula with Outer Ring, left behind by Contraction and Consequent Quickening of Rotation 185
88. Central Condensation Surrounded by Rings 186
89. Rings Collapsing into Planets, and Central Condensation Turning to a Luminous Sun 187
90. Solar System as it is now 188
95. Earth-tides, if the Day and Month Were Equal 213
96. Acceleration of Moon by Forward Pull of Earth-tide 214
97. Loop in Apparent Path of Mars 215
98. Diagram Showing Cause of Loop in Apparent Path of Mars . 216
99. A Celestial Messenger on a Journey 221
103. Parabolic Orbit of a Free Comet 227
104. Elliptical Orbits of Captive Comets 228
105. Tail of a Comet near Perihelion 229
108. A Meteor Bursting in the Atmosphere 230
110. Relative Sizes of Planets 234
111. Relative Sizes of Sun, Jupiter, and Earth 235
112. Relative Sizes of the First Four Asteroids and the Earth's Satellite 236
115. Section of Earthly Volcanoes 251
116. Section of Lunar Volcano in full Activity 252
119. Section of Mountain of Exudation 254
120. Section of Mountain of Elevation 254
121. Section of Lunar Crater with Cone 255

HOW TO KNOW THE STARRY HEAVENS

CHAPTER I

APPARENT MOTIONS OF THE HEAVENLY BODIES AS SHOWN BY OBSERVATION

"Appearances are deceptive." — *Old Saying.*
"Ne jugez pas selon l'apparence, mais jugez selon la justice."
— *Fourth Gospel*, vii, 24 (Ségond).
"Things are not what they seem." — *Longfellow.*

SUPERFICIAL APPEARANCES

BEFORE describing the Universe *as it is*, I wish to say a few words about the Universe *as it seems*. We shall then be better able to judge as to the reasonableness, or otherwise, of the various theories which have from time to time been brought forward to explain the celestial phenomena which are going on around us. It may be well also, before dealing with the dimensions of the Universe, to give a very brief account of the methods used by astronomers to enable them to ascertain the distances and dimensions of those celestial bodies which are within a measurable distance of our World.

The conclusions at which modern astronomy has arrived are not those which would naturally occur to the first observers of the heavenly bodies. The conditions, indeed, are such that superficial observations always lead to wrong conclusions. To-day, in most of our so-called civilised countries, the people in general take it for granted that the Earth is a planet going around the Sun. Many of them have also heard that the stars are far-off suns, floating in practically empty space. Yet not one person

in a thousand truly realises what these statements mean. They are merely hearsay, accepted in childlike faith, as some of the ancients accepted the statement that the Earth is supported by a number of elephants standing on the back of a big turtle *whose legs reach all the way down!*

But in those countries where the secular schools have not familiarised the people with the accepted teachings of modern astronomy, a man who asserts to-day that the Earth goes around the Sun is regarded as either a wag or a lunatic. If people condescend to argue the point with him, they can overwhelm him with apparently good reasons for their incredulity. They can not only give plausible arguments from their own surroundings and experiences, but can also prove their case by wholesale quotations from the writings of the "inspired" priests and prophets of former times. If he suggests that their surroundings and experiences are wrongly interpreted, they laugh him to scorn. If he insists that the ancient writers were ignorant and mistaken, they abuse him as an infidel. If, to avoid their resentment, he tells them that the writers of their sacred books did not intend that their statements should be understood literally, they truly and philosophically reply that he is wresting the Scriptures to his own destruction.

ONLY FACTS WANTED

Seekers after *truth* should not be satisfied with mere hearsay. Those who expect to get *facts* by *faith* alone generally accumulate *fables* instead of facts. Where faith is relied on, it is a mere matter of where we are born as to what we believe. Faith may possibly do no harm as regards immaterial or childish beliefs, but it is very hurtful when used for material or important matters, which require intelligent scepticism to enable us to sort out the true from the false.

Even if by accident we should get the Truth by faith alone, it would do us no good. One of the founders of Christianity told his followers to "*prove all things*," and "hold fast that which is good" (I Thess. v, 21). A better precept was never

given, though many who profess to walk in his footsteps do not seem very enthusiastic about following his counsel.

Those who are looking for *actual facts* concerning the Universe should therefore leave faith to those who are satisfied with *pleasant fables* and *flattering delusions*. They should endeavour, by all the means at their command, to ascertain for themselves whether these things are truly as represented, and they should also try to realise what the facts of the case really involve.

THE MUSIC OF THE SPHERES

As regards the shape of our Earth, it is not now necessary to prove that it is a sphere. Many of us have travelled enough to satisfy ourselves by actual experience as to its general size and shape. Even those who have lived all their lives in one locality have now plenty of positive evidence that the old theory of its being flat is untenable. As regards the rest of the Universe, however, we still have to rely on observation and abstract reasoning.

In order to ascertain whether the sky is a hollow rotating sphere surrounding the Earth, or whether it is, as now claimed, a boundless ocean swarming with suns and worlds, let us examine it and the various objects which appear to be "fixed" to it, or to be wandering around on it.

The most noticeable of the permanent objects in the sky are known as the Sun and Moon.

The most numerous and steadfast are called the *"fixed" stars*. They were so named because they do not appear to change places relatively to one another.

A few objects which very much resemble the stars in appearance are distinguishable from them by several peculiarities. For example, they do not twinkle like the stars, but shine with a steady unflinching light. At some periods they shine very much more brilliantly than at other times. And they slowly change their places among the "fixed" stars. For this latter reason they are known as *planets*, or "wanderers." The best

known of them go by the names of Latin deities who were formerly identified with them. They are called Saturn, Jupiter, Mars, Venus, and Mercury.

Oft-repeated observations of the heavenly bodies, from different parts of our globe, long since proved that they all appear to have certain definite and well-defined motions which have been repeated over and over again for hundreds and thousands of years. There are, to be sure, certain irregularities in some of these motions, but close and long-continued observations show that even these irregularities are themselves regular and cyclic in their action.

STELLAR MUSIC

The most obvious of these motions may be imitated by taking two twelve-ribbed umbrellas (real or imaginary), opening them both, and tying their handles together, so that the arrangement forms a kind of globe (see Figure 2).

On the Equator.—If the observer lives on the Equator, in that hot circle of the Earth which lies between the Tropics, he can represent the apparent motion of the star-strewn "sphere" by keeping the handles of his umbrellas horizontal in a north-and-south direction, and slowly spinning the whole thing around on its handles, so that the rims of the umbrellas rise in the east and descend in the west.

The names of the various groups of stars can be chalked on the inside of the umbrellas, and the observer must imagine himself standing (in the centre of the apparatus) on a flat table which prevents him from seeing anything below his own level. The chalk-marks which are near the rims of the umbrellas will then seem to rise in the east, pass overhead, and sink in the west. Those farther north and south will pass more slowly over the handles or "poles" of the apparatus, which lie flat on the central table and do not change their position at all.

So long as the observer stays on the Equator there will be no change in the position of the starry sphere, which appears

to turn completely over *in about four minutes less than twenty-four hours.*[1]

It is obvious that, if we turn our apparatus so as to keep up with the stars, a fresh rib will pass the Zenith, or point overhead, every two hours (nearly), and that at the same instant

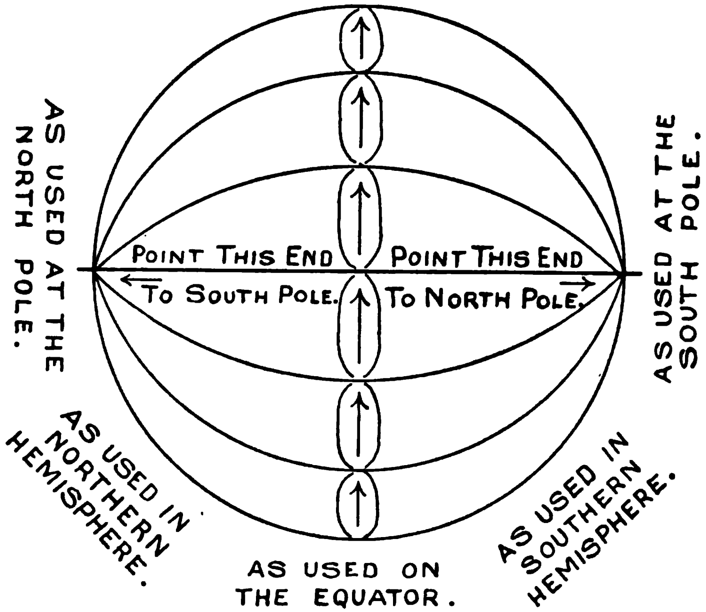


Fig. 2.—Umbrella-Apparatus for Illustrating (Apparent) Star Movements

Face the west when using this diagram. By reversing the points of the compass as here given, and facing the *east*, it will represent the Earth's real motion.

the opposite rib will pass the Nadir, or point below. Also that one rib will rise above the eastern horizon at the same time, while another will descend below the western horizon.

[1] If it were not for these four minutes' difference we should see the same stars, in the same part of the sky, at the same time of the night, the whole year through.

At the North Pole. — But if the observer travels to the north, the apparatus will not follow the motions of the stars unless he tips it up by *raising the northern umbrella.* By the time he reaches the frozen regions near the North Pole, he will have to tip up the apparatus so much that the handles will be perpendicular. The southern umbrella will then be below, *out of sight,* and the chalk-marks on the northern umbrella will turn around the point overhead. If the observer now holds his watch overhead, with the face down, he will find that the chalk-marks are going *the opposite way* to the hands of the watch.

At the South Pole. — If the observer returns to the Equator, he will have to turn the northern umbrella down again, and when he sails into the southern seas *the southern umbrella will have to be tipped up,* to represent the motions of the stars. By the time he reaches the frozen regions around the South Pole, the southern umbrella will be uppermost. A fresh set of chalk-marks will then turn around the point over his head, and they will be found to turn *the same way* that the hands of the watch revolve when looked at from below.

During these supposed journeys from the Equator to the Poles, the axis of the apparatus *will not really be tipped up either way,* for the northern stick will point to the North Pole-Star all the time, and the southern stick will be directed toward the same part of the southern skies all the time. The *apparent* tipping up and down is due to the fact that the surface of the Earth is not flat, but round, and therefore dips toward the Poles. The annexed diagram will show this clearly, the large circle representing the Earth, and the five small objects representing our umbrellas in different parts of the world (see Figure 3).

SOLAR MUSIC

On the Equator. — Let us suppose that the observer is again on the Equator with his apparatus, and that he wishes to follow the motions of the Sun. It will be necessary to put a hoop over the umbrellas where the twelve pairs of ribs come together.

This hoop will represent the Celestial Equator. The ribs of the umbrellas should be numbered from 1 to 12.

Spring "Passover." — If it is about the 20th of March, the Sun's position can be represented by hanging a small electric light where the equatorial hoop crosses the *first* pair of ribs. On turning the apparatus as before, the electric light will rise in the east, pass overhead, and set in the west. While it is

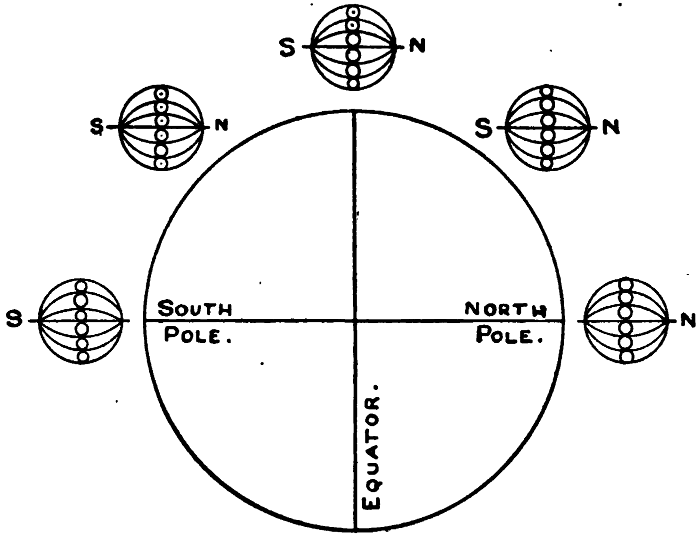


FIG. 3.—THE EARTH, SHOWING RELATIVE POSITIONS OF APPARATUS WHEN USED AT EQUATOR, POLES, ETC.

above the level of the imaginary observer in the centre of the apparatus, the chalk-marks representing the stars must be supposed to be out of sight, on account of the greater brilliancy of the electric light. When it sets in the west, the chalk-marks above the horizon must be supposed to come into view again.

Autumnal Equinox. — Six months later — about September 22 — the arrangement will be the same, except that the

light will have to be shifted to where the equatorial hoop crosses the opposite or *seventh* pair of ribs. That is to say, if the light was where the *first* pair of ribs come together in March, it will be where the opposite or *seventh* pair of ribs come together in September.

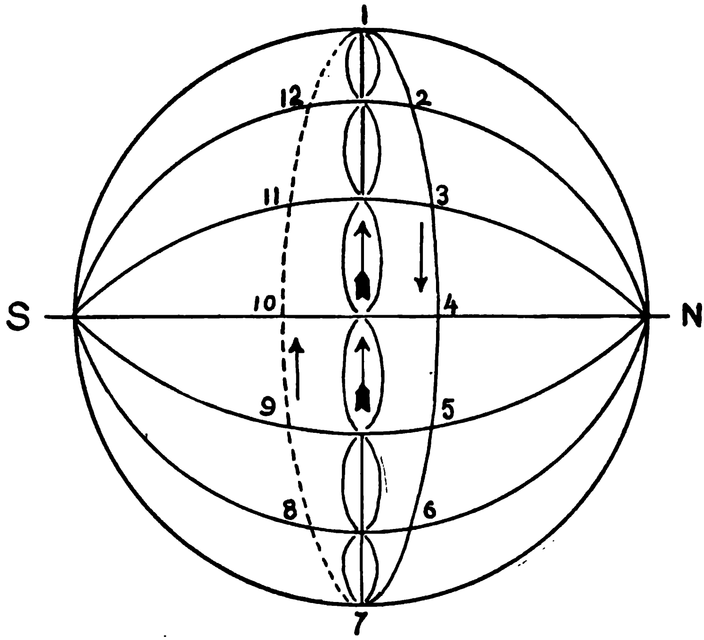


FIG. 4.—UMBRELLA-APPARATUS MODIFIED FOR ILLUSTRATING APPARENT MOVEMENTS OF SUN AND PLANETS

Face the west when using this diagram. If used north of the Equator, raise (N) till it points to the North Pole, and *vice versa*. The feathered arrows indicate the *diurnal* motion; the plain arrows indicate the *annual* motion.

Midsummer Solstice.—About June 21 the light will be on the *fourth* rib, but will be some distance *north* of the equatorial belt.

Yuletide Solstice.—About December 21 it will be on the *tenth* rib, but some distance *south* of the equatorial belt.

If a second hoop be passed over the umbrellas, so that it will pass over these four places, it will represent the Ecliptic, or annual path of the Sun among the stars (see Figure 4).

It will be seen that the light representing the Sun does not go its daily round exactly the same as the chalk-marks representing the stars. It moves slowly backward on the second

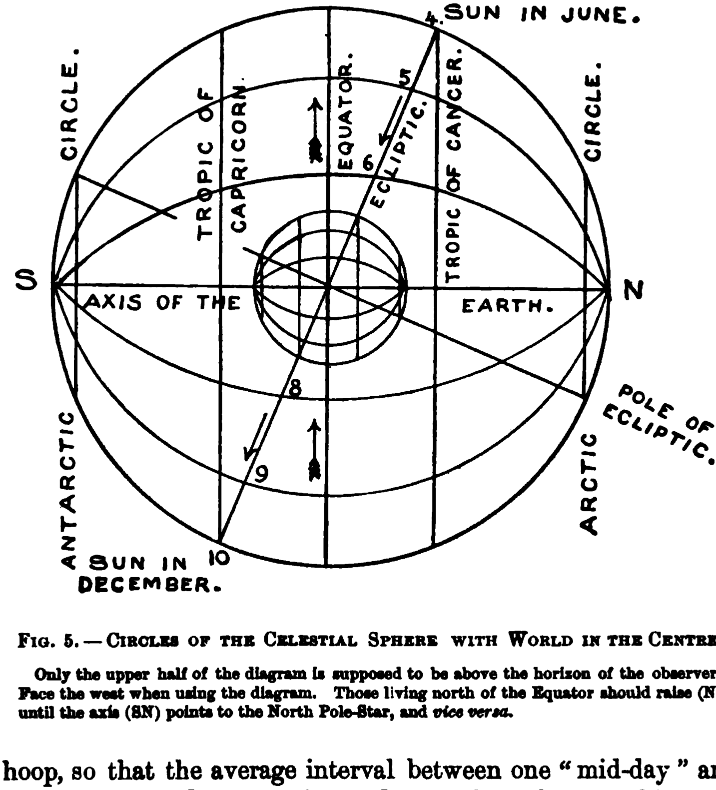


Fig. 5. — Circles of the Celestial Sphere with World in the Centre

Only the upper half of the diagram is supposed to be above the horizon of the observer. Face the west when using the diagram. Those living north of the Equator should raise (N) until the axis (SN) points to the North Pole-Star, and *vice versa*.

hoop, so that the average interval between one "mid-day" and the next is nearly four minutes longer than the "southing" of one of the chalk-marks on two successive "nights." The result is that in the course of 366¼ revolutions of the umbrellas, which represent the star-sphere, there are only 365¼ revolutions

of the light which represents the Sun. In other words, the Sun, whose motions we are trying to represent, creeps slowly back along the Ecliptic, so that in exactly one year it has lost one revolution, having gone completely around the "star-sphere" to the place where it was twelve months before.

As the Sun's path is not on a line with the Equator, but crosses it obliquely, the Sun not only loses one complete revolution in a year, but also drifts to the north and south of the equatorial belt, which it "passes over" twice in each year, at the spring and autumn "Passover" or Equinox (see Figure 5).

"THE BURNING ROW"

In the apparatus just used, the hoop along which the light slowly travels represents the Celestial Ecliptic, or path of the Sun. This hoop lies over twelve sets of chalk-marks representing twelve different constellations of stars. Each set of stars has a name by which it has been known for several thousands of years. The twelve form what are collectively known as the Signs of the Zodiac. They are also known as the Twelve Houses (or Mansions) of the Sun. The Book of Job (xxxviii, 32) mentions them under the name of the *Mazzaroth.*

It takes the Sun a *solar month* (a little longer than a *lunar month*) to travel through each "house" or constellation. In March the Sun enters the constellation known by the Latin name for Fishes (*Pisces*); in June it gets to the group known as the Twins (*Gemini*); in September it reaches the Virgin (*Virgo*); in December it is with the Archer (*Sagittarius*); and the following March it enters once more the constellation of Pisces.[1]

[1] The Sun is commonly said to be at the "*First Point of Aries*" (the Ram) at the Spring Equinox. This is true only at certain long distant intervals, as will be explained in Chapter XII. The "point" has reference to the Earth's orbit, and not to the stars. It was named after the constellation which happened *at the time* to be beyond the Sun in March.

LUNAR MUSIC

The positions and motions of the Moon are about the same as those of the Sun, only the Moon hangs back more and loses a revolution in a lunar "moonth," or month, instead of losing one in a year. In its backward drift it therefore catches up with the Sun nearly thirteen times in a solar year.

Eclipses. — The various phases of the Moon show that it is a dark body, like our Earth, lighted up on one side by the Sun. They also show that it is nearer to us than the Sun. Sometimes, indeed, it passes *exactly* between us and the Sun, producing what is known as an *Eclipse of the Sun.* When it is *opposite* to the Sun, the shadow of the Earth sometimes falls on it, producing what is known as an *Eclipse of the Moon.* The reason why there is not an eclipse at every "conjunction" and "opposition" of the Sun and Moon is that the path of the latter, although nearly on the same plane as that of the Sun, does not *exactly* coincide with it. The two paths, therefore, appear to cross or intersect, in the same way that the Ecliptic and the Equator cross each other.

PLANETARY MUSIC

The larger planets all keep on or near the Sun's path, but their apparent motions are more irregular, and each has a period of its own, varying from a few months to many generations.

Those known as Mercury and Venus appear to drift backward and forward on each side of the Sun. They never go very far from it, and are therefore seen only shortly before sunrise or soon after sunset.

The other planets appear to drift eastward among the stars that lie along the path of the Sun and Moon. But when they get nearly opposite to the Sun (that is, when they pass the south about midnight) this eastward drift is reversed for a time, so that each planet appears to make a loop in the star-sphere. But they never go far away from the Ecliptic, or path of the Sun (see Figure 97).

North and South of the Equator. — If our observer takes his apparatus north or south of the Equator, and tips it up as before, when observing the stars, he will find that the positions and motions of Sun, Moon, and planets can all be approximately marked out on the hoop that represents the Ecliptic. This will be true for any and every part of the Earth's surface. The Moon and the large planets are *never found in any other part of the sky* than on (or close to) the Sun's path, or Ecliptic. The same apparatus will show why the days are long *in June* north of the Equator, and long *in December* to the south of that line.

Going East and West. — So far the observer has travelled only north and south. If he travels to the east or west, he will find that no change is needed in his apparatus so long as he does not change his latitude.

On the Equator, for example, the motions of the heavenly bodies are the same whether the observer is in Africa, the East Indies, or in America. The only difference is in *time.* If he could telegraph from equatorial Africa at midnight, and get immediate answers from the East Indies and America, he would find that it was already sunrise in the East Indies, whilst it was only sunset in equatorial America. With this exception the phenomena observed are alike on all parts of the Earth lying under the Equator. The same is true of any other latitude.

Although our apparatus represents very fairly the *angular* distances and *apparent* motions of the heavenly bodies, it does not directly throw any light on their *actual* distances or *real* motions.

A PRIMITIVE EQUATORIAL

It will be well for all who have not made a study of the above phenomena to observe for themselves as many of these apparent motions as can be seen from the part of the world they may happen to live in. All the apparatus that is really necessary is a straight stick set firmly in the ground (or otherwise supported) at such an angle that it will point to the Pole

Star, and a tube (or telescope) attached to it so that it can be moved in any direction. The tube or telescope can then be rotated so as to follow the diurnal motion of any of the heavenly bodies. When the tube is at right angles to its support it is pointing to the celestial Equator (see Figure 6). Rude

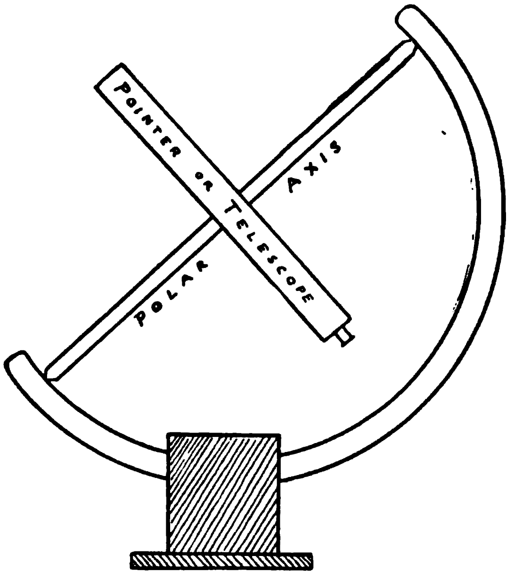


FIG. 6.—AN ADJUSTABLE EQUATORIAL, SUITABLE FOR ANY PART OF THE WORLD

The axis is clamped in such a position that its ends point to the poles of the heavens.

as this method of observation may seem, it is capable of leading intelligent observers to a correct solution of the main problems of astronomy.

A very interesting method of observing the daily motions of the stars is to point a camera to some part of the sky on a clear starlight night, and leave the plate exposed for an hour or so. On developing the print it will be found that each star has left a trail on the plate. Figure 7 is a photograph of the stars sur-

rounding the North Pole. The further the star is from the centre of rotation, the longer and straighter is the trail it makes on the plate.

Figure 8 shows the constellation of the Great Bear (or the Dipper, as it is often called), repeated four times, to show its position in the northern skies every six hours. It will be seen that the two "Pointers" are always in a straight line with the star which happens to be near the axis of rotation. This star is commonly known as (Stella) Polaris, or the Pole Star.

Fig. 7. — Northern Star-Trails
Photographed by Barnard, with twelve hours' exposure.

Fig. 8. — The Dipper, or Great Bear, at Intervals of Six Hours
It will be seen that the two "pointers" are always in a line with the Pole-star.

CHAPTER II

RIVAL THEORIES TO EXPLAIN THE APPARENT MOTIONS OF THE HEAVENLY BODIES

(*A*) *THE EARTH-CENTRED THEORIES OF THE UNIVERSE*

"Then the Evening (*Erev*) and the Morning (*Voker*) brought to a close the Third Day (*Yom*).

"And the Mighty Ones (*Elohim*) said: 'Let there be luminaries in the Hammered Plate (*Rakia*) of the sky, to separate the Day (*Yom*) from the Night (*Lylah*);[1] let them be for signs and to mark the seasons, Days (*Yamim*), and years; let them serve as luminaries, in the Hammered Plate of the sky, to give light upon the Earth.' And it was so.

"And the Mighty Ones made two great luminaries, the larger one to preside over the Day (*Yom*), and the smaller one over the Night (*Lylah*). [They made] *the stars also.*

"The Mighty Ones placed them in the Hammered Plate of the sky, to give light upon the Earth, to preside over the Day (*Yom*), and the Night (*Lylah*), and to separate the light from the darkness. The Mighty Ones saw that it was good.

"Then the Evening (*Erev*) and the Morning (*Voker*) brought to a close the Fourth Day (*Yom*)."—*Book of Origins*, I, 13–19 (*A. Zazel's Translation*).

EARLY FLAT-WORLD SUPPOSITIONS

IN trying to explain the observed motions real (or apparent) of the heavenly bodies the ancients were handicapped by their ignorance of the world itself. This appeared, from their local standpoint, to be a flat though uneven surface, the lower parts of which were filled with water. Their experiences on this Earth also prevented them from realising the possibility of anything solid and heavy remaining suspended in space without falling anywhere. Their entire ignorance as to the nature, dimensions, and distances of the celestial bodies led them to

[1] *Lylah* was personified by the Israelites as *Lilith*, the first wife of Adam. Isaiah xxxiv, 14 (R. V.—Margin).

suppose that they were put in the heavens by somebody to throw light on the Earth, or to relieve the monotony of the sky. With them the Earth itself was the Universe, and even those who recognised the importance of some of the most prominent celestial objects made the natural mistake of supposing them to be Gods who ruled the Earth from their thrones on high.

UNDERLYING FACTS

Yet even three and four thousand years agone there were individuals who had discovered that "things are not what they seem." Some of the real facts relating to the Universe were known to a few learned men among the ancient Babylonians, Egyptians, Chinese, Greeks, and Hindus. But the world was not ready for their teachings, and during the Dark Ages that followed the establishment of Christianity the few truths that were known were trampled under foot, like pearls cast before swine.

However, trampled pearls are apt to come to light again. Facts are stubborn things, and will not permanently down. So the lost facts have been rediscovered in modern times, and largely supplemented by fresh ones.

Let us glance briefly at some of the primitive ideas held by the ancients with regard to the Universe, so that we may compare them with more modern explanations. We can then decide as to which best fit the observed phenomena, and are, on that account, the most deserving of credence.

THE CANOPY THEORY

The world we live in was at first supposed to be *flat*, or nearly so, with a *massive firmament* resting on the mountains at the edge and spanning the whole Earth.

To the ancient Egyptians the sky was the bosom of Neit, a celestial ocean across which the divine Sun, Moon, and planets were carried in boats. In Greece it was supposed to be a solid canopy, across one part of which *Helios*, the Sun-God, daily

drove in a chariot of gold, while his sister *Selene*, the Moon-Goddess, followed him in a chariot of silver. Mount Olympus was supposed to reach up to the highest part of this canopy. On the summit of this holy mountain was the palace of *Zeus*, king of all the Gods. There the Greater Deities abode, ruling the world below to suit themselves, and dealing out a very peculiar kind of justice to the unfortunate mortals who lived thereon.

Ancient books, as a rule, *did not discuss or assert these things*, any more than modern books discuss or assert the conclusions of modern astronomy. They merely *alluded to them*, taking them for granted as well-ascertained facts which were useful for illustration, but which it would be folly to argue about or assert. Thus one of the characters in the Hebrew drama of Job casually mentioned that this firmament was "spread out" (Job ix, 8) "*as strong as a molten mirror*" (Job xxxvii, 18 — R. V.). In the same way the Mohammedan Koran sought to show the fine workmanship of *Allah* by pointing out that he had stretched the firmament across the entire world *without a crack in it.*

The Hebrew word for firmament (*Rakia*) really means *a hammered plate of metal* (Ex. xxxix, 3), and all its Greek and Latin equivalents have a *firm* or *solid* meaning. The modern idea that the writers meant an *expanse* is seen to be absurd when we notice that it was *created* (Gen. i, 1), or *made* (Gen. i, 7); that it was *spread out* over the Earth (Job ix, 8); and that it had *windows* in it (Gen. vii, 11); also that the Tower of Babel was intended to reach up to it (Gen. xi, 4); and that the top of Jacob's ladder rested against it (Gen. xxviii, 12). The mountains which were supposed to support this "hammered plate of heaven" were naturally spoken of as the *pillars of heaven* (Job xxvi, 11).

When the writer of the Apocalypse was describing the approaching end of the world he made an earthquake shake the stars out of this firmament on to the ground "as a fig-tree casteth her unripe figs when she is shaken of a great wind." He ended by letting the heavens roll together, as a scroll does when the ends are released (Rev. vi, 13–14 — R. V.).

The Venerable Bede, an eminent Christian writer of the

seventh century, considered the Earth to be flat (or perhaps convex), with a star-spangled canopy over it. This canopy he supposed to be like an umbrella, with its centre at the Pole Star. The daily motion of the heavenly bodies he explained by supposing the canopy to spin round, like the tent over the "merry-go-rounds" of our country fairs. His ideas on the subject are a curious mixture of accurate observation and childlike speculation. He says:

> "The *Creation* was accomplished in six days. *The Earth is its centre and its primary object.* The Heaven is of a fiery and subtile nature, round and equidistant from every part, as a canopy from the centre of the Earth. It turns round every day with ineffable rapidity, only moderated by the resistance of the seven planets, three above the Sun — Saturn, Jupiter, Mars — then the Sun; three below — Venus, Mercury, the Moon. The stars go round in their fixed courses, the northern perform the shortest circle. The *Highest Heaven* . . . contains the angelic virtues. . . . The *Inferior Heaven* is called the Firmament, because it separates the superincumbent waters from the waters below."

THE CRYSTAL SPHERES

Such were the primitive ideas of unenlightened men with regard to the Universe. Sometimes, however, the problem was investigated in a scientific spirit. It was then readily seen that the celestial phenomena could not be explained on the canopy theory.

Observation, as well as theory, ultimately led to the overthrow of this primitive idea of a solid star-strewn firmament resting on the mountains. For many of these so-called "pillars of heaven" had been ascended, and no "hammered plate of heaven" had been found resting on them.

So new theories arose, each of which came a little nearer the truth than the one before. It was suggested that the world was inside a crystal globe or sphere, to which the stars were attached. The nightly motions of the stars were explained by supposing that this crystal sphere rolled over every twenty-four hours.

This theory explained very well the motions of the stars, but did not fit in with the more varied movements of the Sun, Moon, and five planets. Some explained their irregularities of motion by supposing that they were carried around with the stars, but that, instead of being fixed to the revolving sphere, like the stars, they were at liberty to crawl around on it very slowly, like so

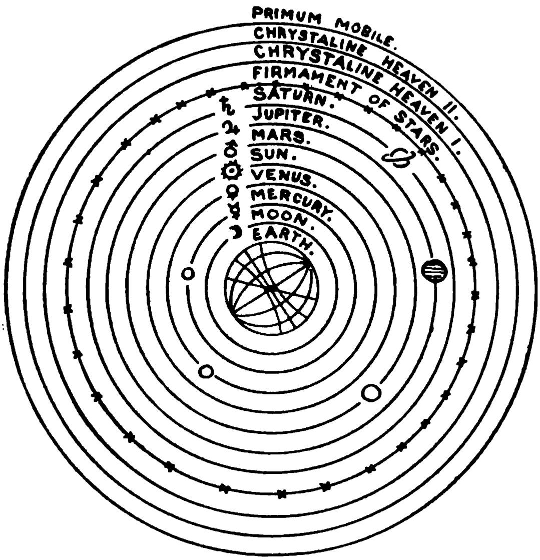


FIG. 9.—THE PTOLEMAIC SYSTEM

many insects. Others suggested that each of these seven wanderers had a crystal sphere all to himself (see II Cor. xii, 2). The seven spheres were supposed to be one inside the other. Each was thought to share in the general daily rotation, but to lag behind or have a slight independent motion of its own (see Figure 9).

Even this far-fetched notion did not fit in satisfactorily with the observed phenomena. So Tycho Brahé suggested that the Earth was a globe, spinning round on its axis every twenty-four

hours; that the Sun and Moon went around the Earth in a year and in a month, respectively; and that the five planets went around the circling Sun (see Figure 10).

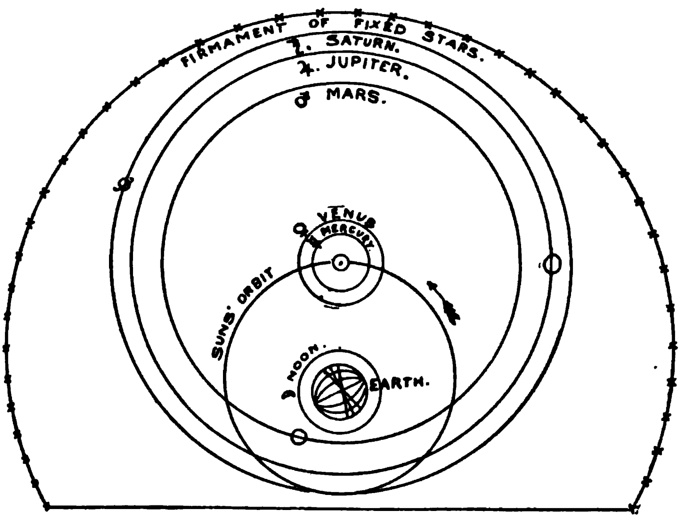


FIG. 10. — THE TYCHONIC SYSTEM

EPICYCLES

As even this complex arrangement did not fit in with the observed motions, the planets were then supposed to move in a series of eccentrics around their ideal orbits, with the star-sphere outside of all. For a time this theory was thought to explain the observed motions. But it was such a complex, improbable, lumbering, incomprehensible, and absurd theory that Alphonso, king of Castile, ventured the remark that if he had been consulted by the Creator he could have considerably improved upon the plan.

FAUSTUS ON THE SPHERES

These mediæval speculations are well illustrated by the following dialogue from Marlowe's "*Faustus*," written toward the close of the sixteenth century.

"*Faust.* Tell me, are there many heavens above the Moon?
Are all celestial bodies but one globe,
As is the substance of this centric Earth?
Mephistopheles. As are the elements, such are the spheres,
Mutually folded in each other's orb.
And, Faustus,
All jointly move upon one axletree,
Whose terminine is termed the World's wide pole:
Nor are the names of Saturn, Mars, or Jupiter
Feign'd, but are erring stars.
Faust. But, tell me, have they all one motion, both *situ et tempore?*
Meph. All jointly move from east to west in twenty-four hours upon the poles of the World, but differ in their motion upon the poles of the zodiac.
Faust. Tush, these slender trifles Wagner can decide:
Hath Mephistopheles no greater skill?
Who knows not the double motion of the planets?
The first is finished in a natural day;
The second thus; as Saturn in thirty years, Jupiter in twelve; Mars in four; the Sun, Venus, and Mercury in a year; the Moon in twenty-eight days. Tush, these are freshmen's suppositions. But, tell me, hath every sphere a dominion or *intelligencia?*
Meph. Aye.
Faust. How many heavens or spheres are there?
Meph. Nine; the seven planets, the firmament, and the empyreal heaven.
Faust. Well, resolve me in this question; why have we not conjunctions, oppositions, aspects, eclipses, all at one time, but in some years we have more, in some less?
Meph. *Per inæqualem motum respectu totius.*
Faust. Well, I am answered."

The writer of a recent magazine article[1] sums up these old ideas of the Universe very neatly. He says:

"To the men of the Middle Ages the world was a little space shut tight within a wheelwork of revolving spheres. It was compendious, complete, ingenious, like a toy in a crystal box. Beyond the outer shell nothing existed. The heavens were uncorruptible. No change could occur in the whole system, save in the Earth alone. The Universe was created for the sole use of man. It was small and finite."

THE ROUND WORLD

While all these speculations were going on, people had been going to and fro on the Earth, and travelling up and down on it. In this way they had discovered for an actual fact that the world is not flat, but is a round ball, 8,000 miles thick, suspended in space, with the starry heavens on every side of it.

This being the case, it follows that *if* the stars *are* fixed to a massive firmament, it is not a mere "dish-cover" or umbrella over a flat Earth, but is in the form of a hollow crystal sphere, rolling over (to the west) every twenty-four hours, with the round World in the centre, supporting itself on nothing.

(B) THE SUN-CENTRED THEORY OF COPERNICUS.

"The first formal assertion of the heliocentric theory was made in a timid manner, strikingly illustrative of the expected opposition. It was by Copernicus, a Prussian, speaking of the revolutions of the heavenly bodies; the year was about 1536. In his preface . . . he complains of the imperfections of the existing system, states that he has sought among ancient writers for a better way, and so had learned the heliocentric theory. . . . In their decree prohibiting [the work of Copernicus], '*De Revolutionibus*,' the Congregation of the Index, March 5, 1616, denounced the new system of the Universe as 'that false Pythagorean doctrine utterly contrary to the Holy Scriptures.' . . . The opinions thus defended by the Inquisition are now objects of derision to the whole civilized world."[2]

[1] Dr. E. S. Holden, in the "Popular Science Monthly," November, 1903.

[2] Dr. J. W. Draper.

"People gave heed to an upstart astrologer who strove to show that the Earth revolves, not the heavens or the firmament, the Sun and Moon. . . . This fool wishes to reverse the entire science of astronomy."[1]

The final outcome of all these speculations was that the whole of the Earth-centred theories were thrown overboard, and replaced by an old Sun-centred theory originally brought from India by Pythagoras. According to this new yet ancient theory, the stars are practically immovable bodies suspended far off in space, and the Sun is the centre around which all the planets, *including the Earth itself*, revolve (see Figure 11).

Fig. 11. — Copernican System

Including four of the most tilted orbits of Minor Planets. Neptune's orbit is here omitted.

It has been found, however, that the Moon does actually go around the Earth, completing a revolution in about a month. The daily motion of all the heavenly bodies is not real, but only apparent. It is explained by the fact that the Earth itself rolls completely over (to the east) every twenty-four hours, at the same time that it travels around the Sun once every year. This daily rotation of the Earth causes all the heavenly bodies to appear to turn in the opposite direction.

The peculiarities of the Sun's annual drift to the north and south, and the resulting seasons, are readily explained by the

[1] Martin Luther.

fact that the Earth has a heavy "list" to one side, with reference to its path around the Sun (see Figure 12). The other planets are also drifting around the Sun, in the same general direction, but at different distances from it.

This Indian system of cosmogony is now known as the *Copernican Theory,* because Copernicus first established its truth in modern Europe. It explains the motions of the heavenly bodies so well that there is no doubt about its being true as far as it

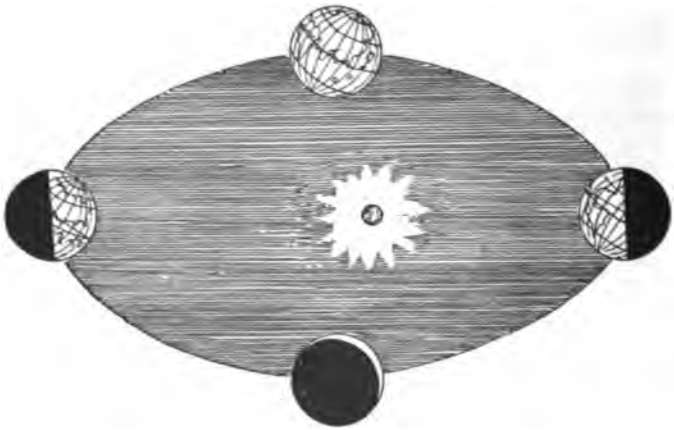


FIG. 12. — RELATIVE POSITIONS OF EARTH AND SUN AT THE FOUR SEASONS

goes. In spite of the long-continued opposition of unprogressive theologians, it has now been adopted by all competent judges, and is accepted, *on hearsay*, even by those who do not realise the subordinate position to which it reduces our Earth, and by those who do not profess to be competent to judge as to its correctness.

The adoption of this theory has led to the solution of a multitude of otherwise inexplicable phenomena. Without it, the planetary bodies appeared to be swinging around us in a labyrinth of perplexing knots and meaningless tangles. As a result of its adoption, the knots and tangles have all been unravelled, and the structure and dimensions of the Solar System have been

tolerably well ascertained. The telescope and other opitical instruments have now greatly increased our knowledge of the heavenly bodies generally, and have revealed to us similar systems moving in actual conformity with the Copernican Theory.

This same theory has also enabled astronomers to apply themselves, not entirely without success, to the task of ascertaining the structure, and measuring the distances and dimensions, of the more distant luminaries known to us by the misleading name of "fixed stars."

Every observed peculiarity is explained by this theory, without any absurd and impossible suppositions like the "eccentrics" and "epicycles" of other theories. And many facts have been discovered by following it up to its logical conclusions. It is therefore the true explanation of the mechanism of the Universe.

How and *why* these movements of the heavenly bodies are kept up will be briefly dealt with in subsequent chapters.

CHAPTER III

PRINCIPLES UTILISED FOR MEASURING THE UNIVERSE

"And there was given me a reed like unto a rod, and the angel stood, saying, Rise and measure the temple of God." — *Rev.* xi, 1.

"And he that talked with me had a golden reed to measure the city, . . . and he measured the city with the reed, twelve thousand furlongs. The length and the breadth and the height of it are equal." — *Rev.* xxi, 15, 16.

"The measure of the Moon's distance involves no principle more abstruse than the measure of the distance of a tree on the opposite side of a river." — *Sir George Airy.*

HOW IT IS DONE

I WILL now say a few words about the way in which astronomers have been enabled to find out the distances and dimensions of many of the objects which compose the Universe.

It was very early recognised that the heavenly bodies are not all at the same distance from us.

STARS ARE BEYOND PLANETS

The stars, for example, have a far-away look and a fixity of position that would naturally lead one to think that they were beyond the larger, brighter, and more active luminaries which are found on or near the Ecliptic. This was proved beyond a doubt when observers at a distance from one another compared notes. For it was sometimes found that when an observer in the *north* saw a certain planet a little to the *south* of a particular star, an observer in the *south* would see it *north* of the same star. The only possible explanation of this is that the planet is nearer to us than the stars.

THE ORDER OF THE PLANETS

Leaving the "fixed" stars out, there were seven celestial "wanderers" known to the ancients. Of these, two appear to

be very much nearer to us than the other five. The Sun, for example, is evidently either very near or very large, bright, and hot. But the Moon is nearer to us than the Sun, for it sometimes passes in front and shuts off its light and heat from us. As it also passes between us and every other celestial object that comes in its way, it is evidently the nearest of all the heavenly bodies.

Now the Moon performs its circuit of the heavens in less time than any other wanderer. It seems natural, then, to suppose that the wanderers which take the most time to perform their circuit are the farthest away from their common centre of revolution.

This reasoning led the early astronomers to regard slow-moving Saturn as the most distant planet. The stately Jupiter they put next, followed by fiery Mars. As regards the other three, there was some difference of opinion, due to the fact that, on the Earth-centre theory, their real motions were not distinguished from their apparent ones, due to perspective.

But when once it was recognized that the Sun was the centre around which the planets turned, it became evident that our own populous Earth and pale-faced Moon were travelling in partnership, next to Mars; that "Venus the beautiful" followed; and that fast-flying Mercury kept nearest to the central Sun.

COMPARATIVE DISTANCES

The order of the planets being thus settled, the next thing was to ascertain their distances from the Sun.

In the case of the *inferior* or *inner* planets, Mercury and Venus, their proportional distances from the Sun were easily found. All that had to be done was to point one leg of a pair of dividers, or compasses, at the setting or rising Sun, and the other leg at the planet Venus when at its greatest angular distance from it, as an Evening or Morning Star. The dividers were then laid on a sheet of paper, and two lines drawn to indicate the V shape of the open dividers (see S E V in Figure 13).

The Earth was then supposed to be at E, where the two lines come together, and the Sun was supposed to be at the other end (S) of one of the lines. Venus would evidently be somewhere on the line E V.

Taking it for granted that the planetary orbits were circular, a circle was then drawn through E from S as a centre. This represented the Earth's orbit. Another and smaller circle was drawn from the same centre, just large enough to touch the other arm, E V. This circle evidently represented the orbit of the planet Venus.

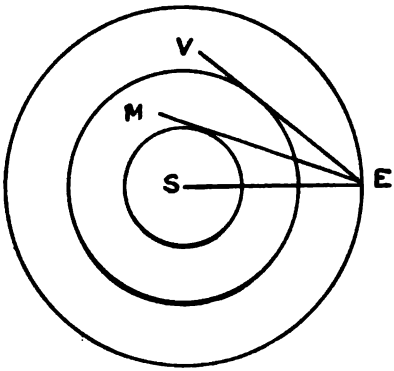


FIG. 13.—ORBITS OF MERCURY, VENUS, AND EARTH

The same process was gone through with the planet Mercury, and the result transferred to the same figure (see S E M).

On measuring the radii or semi-diameters of these three circles, representing the planetary orbits, it was found that their lengths varied in the ratio of 100, 72, and 38. These figures, therefore, represent the relative distances of the Earth, Venus, and Mercury.

A comparison of the *distances* with the *times of revolution* then enabled the relative distances of the *superior* or outer planets to be computed by means of *their* times of revolution, taking it for granted that they all obeyed the same law, whatever that law might be.

The result was that the distances of the outer planets, when computed on the same scale as the inner ones (= 100 to the Earth's distance), were found to be 152, 520, and 953.

PLANETS MOVE IN ELLIPSES

It may be as well to state here, that while the above observations were being made it was discovered that the orbits of the inner planets are not exactly circular, but slightly egg-shaped, or, rather, elliptical. It has since been found that the paths of all the planets share this peculiarity, the cause of which has also been ascertained.

NEWLY DISCOVERED PLANETS

Since the invention of the telescope two large planets have been discovered beyond the orbit of Saturn. They bear the names of Uranus and Neptune. On the same scale as that used above, their distances from the Sun are represented by the numbers 1,920 and 3,000.

A great number of small planets have also been discovered in the interval between the orbits of Mars and Jupiter. Their numbers are so great, their sizes so small, and their orbits so peculiar, that astronomers formerly looked upon them as the scattered fragments of larger planets which had met with an accident.[1]

ACTUAL DISTANCES

The *comparative* distances of all the planets having been thus discovered, all that had to be done was to find the *real* distance of one of them in miles. All the other distances could then be readily computed in miles.

It took many generations to solve this little problem, and even yet the answer is not as free from error as could be wished. It has, however, been solved, with a very fair amount of accuracy, by several independent methods. The distances usually measured are those of the neighbouring planets when they are at their least distances from us or are otherwise favourably placed.

[1] The orbits of four of these "Asteroids" are shown in Figure 11. It will be noticed that the four represented do not lie in the same general plane as those of the larger planets, but are more or less tilted up, some one way, and some another. These, however, are exceptions. The majority move in or near the general plane.

There are many people who do not put much faith in celestial measures. They cannot see any possibility of obtaining them, seeing that we cannot stretch a tape-line from one flying world to another. There are, however, a number of ways in which inaccessible distances may be accurately measured. For example, if you wish to measure the height of a tree without ascending it, all you have to do, if the ground is level, is to put a stick upright in the sunshine, and measure the length of its shadow. If a three-foot upright makes a three-foot shadow, then a hundred-foot shadow indicates that the tree which casts it is a hundred feet high. And if the Sun is so low down that the three-foot stick makes a six-foot shadow, then a two-hundred-foot shadow will indicate that the tree which casts it is a hundred feet high.

There are other methods which are just as simple, though most of them require more elaborate apparatus. A little study will show that celestial and other inaccessible measurements may be as accurate as any made with the help of a chain or tape-line. Let us see what are the principles involved and methods employed.

ESTIMATING DISTANCES

If you close one eye and keep your head still, you will find that with one eye alone you will be unable to judge as to the distance from you of the object you are looking at. The only exception to this is, that if you already know the size of the object you can estimate its distance by noticing whether it appears to be large or small.

To be able to estimate your distance from any object, you must either move your head or open the other eye, so as to get another picture of it to compare with the image already obtained. Then you can estimate with a tolerable amount of accuracy how far the object is from you (see Figure 14).

The two eyes form the extremity of a three-inch base-line, and if you draw an imaginary line from each eye to the point you are looking at, you will obtain a three-cornered or triangular

figure of known dimensions. That is, you will know (approximately) the length of all its three sides.

LAND-SURVEYING

The surveyor, when he wishes to find the width of a river without crossing to the other side, measures off a base-line on his own side of the stream. Then, by noting with his instruments the position of an object on the other side of the river, as seen from each end of his base-line, he can tell how wide the river is.

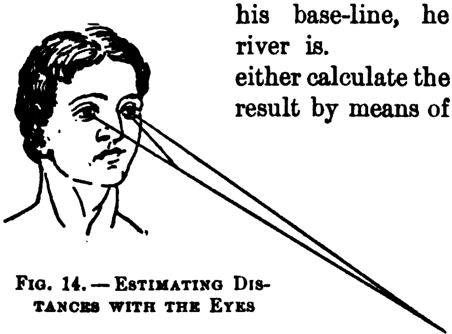


FIG. 14. — ESTIMATING DISTANCES WITH THE EYES

In this case he can either calculate the distance, or get the result by means of a diagram on paper. If he wishes to do the latter, he draws a line to represent his base-line, and from each end of it sets off a line *at the same inclination or angle* to it as that used on his real base-line. The place where these two lines cross each other represents the position of the object observed on the other side of the river (see Figure 15). By measuring the sides of his triangle he gets the distance required in terms of his base. For instance, if the sides of his triangle are 10 times as long as the base thereof, and the latter is 10 yards long, then the width of the river is 100 yards.[1]

A whole continent can be surveyed in the same way, by measuring off three-cornered areas of land, and using every distance obtained as a base to measure other distances with. In this way (with certain details and precautions which need not be here specified) the shape and size of the Earth can be obtained.

[1] A right-angled triangle gives the best results. Those who wish for further details will find them in the next chapter, which is written for those who are not afraid of a little simplified trigonometry and diluted mathematics.

SKY-SURVEYING

The astronomer then finds out the distance of the Moon in the same way, by using a measured base-line about 4,000 miles long. As he cannot see one end of his base-line from the other end of it, he gets his angles indirectly, by polar distances, or by observing how much the Moon is displaced among the stars when viewed from different parts of the world at the same time.

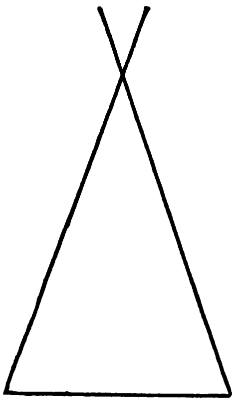


Fig. 15. — Surveying from a Base-line

The same principle, rather differently applied, enables him to tell the distance of the Sun.

With a 4,000-mile base-line the Moon's distance is found to be *about* 60 times as long as the base-line. On multiplying 4,000 by 60 we get the Moon's distance, 240,000 miles.[1]

With the same base-line of 4,000 miles the Sun's distance is found to be about 388 times greater than that of the Moon. It will be seen that the longest base-line we can get is very short when compared with the distance to be measured; but as it is the longest available, astronomers have to make up for its shortness by using different methods and taking advantage of every favourable opportunity to correct their measurements. Now 388 times 240,000 comes to *about* 93,000,000 miles, which is *approximately* the Earth's distance from the Sun.

As we already know the *comparative* distances of the other planets from the Sun, their *actual* distances can now be obtained without difficulty.

The following table gives in one column the relative distances of the planets, the Earth's distance being represented by 1.000. In another column it gives the real distances in miles. They are calculated according to the most recent estimates of the solar *parallax*, which will be explained in the next chapter.

[1] These figures are not exact, but will serve to show the principles involved.

PLANETARY DISTANCES

(Solar Parallax, 8.81″)

	RELATIVE	ACTUAL (IN MILES)
Mercury	.387	35,909,000
Venus	.723	67,087,000
Earth	1.000	92,790,000
Mars	1.523	141,384,000
Asteroids	2.080	193,000,000
	4.262	395,470,000
Jupiter	5.203	482,786,000
Saturn	9.538	885,105,000
Uranus	19.183	1,779,990,000
Neptune	30.055	2,788,800,000

It will be seen by those who have followed the argument thus far that there is no guessing about the process. It is a mere matter of observation and calculation. In the first instance given, the width of the river can be found by stretching a cord across it, or the result can be tested in various other ways. In the case of the Sun, Moon, and planets, the results can also be tested in other ways, as well as by repeating the experiment under different conditions. As soon as the observations can be carried out *without error*, the distances can be obtained *exactly*. But not before.[1]

STAR DISTANCES

The stars are too far off for their distances to be measured by a 4,000-mile base-line. But as it is found that the Earth in January is at an enormous distance from the place which it occupies in July, the positions of the stars are observed at both periods, and compared together.

[1] A few years ago it was discovered that one of the asteroids, or minor planets, which goes by the name of Eros, moves in an elongated orbit, one part of which is nearer to us than that of Mars. At certain periods this planet (which is only about twenty miles thick) comes within a distance of 14,000,000 miles from the Earth. By its means celestial distances will before long be much more accurately known than they are now.

This gives a base-line of nearly 186,000,000 miles. But even with this gigantic base there are only a few of the nearest stars whose distances can be even approximately estimated. The distance of the nearest of them is about 135,000 times as great as the length of our enormous base-line. It is 9,000 times as far off as Neptune, the outside planet in our system. About sixty stars have measurable parallaxes, a few more have perceptible ones, but all the others are at present out of reach in the unsoundable depths of infinite space.

If our eyes were as powerful and accurate as the instruments of the astronomer, we could look at a shining grain of sand thirty miles away, and estimate its distance from us by observing how much the eyes had to be drawn together to focus on the object.

The same principle of triangulation which enables a surveyor to plot off a township or measure the height of a mountain enables the astronomer to measure the world and ascertain the distances of the Sun, Moon, planets, and some of the stars. Enormous as many of the distances are, all these measurements depend on an ordinary yard-stick,—they are all based on the common three-foot rule.

"E PUR SI MUOVE"

It should be observed that the above-described method of measuring the distances of the heavenly bodies will in some cases give the same results whether we suppose the Earth to stand still, with the Sun, Moon, planets, and stars swinging around it once every twenty-four hours, or whether we suppose that the diurnal changes are caused by the Earth revolving on its axis.

But, having once found the distances, it is evident that the latter is the true explanation of the phenomena. For if the planet Neptune — distant as it is — really goes around the Earth in a day, it must go at the unthinkable speed of 190,000 miles in a second of time. And if the stars, whose distances are so much greater than that of Neptune, also go around the Earth

every day, their speed must be thousands and millions of times faster still.

On the other hand, if it is the Earth that revolves, the motion is nowhere greater than one mile in three seconds. The probabilities are evidently altogether in favour of the latter proposition. The former one is impossible and absurd.

There is only one way of getting over the difficulty. In spite of all who deny it, or fail to realise it, the fact still remains that "the Earth does move."

MEASURING THE PLANETS

While measuring the distances of the Sun and planets, astronomers have been able, by measuring their *apparent* diameters (in degrees, minutes, and seconds of arc), to ascertain their *real* diameters in miles. The principle is a very simple one, and may be illustrated in this way.

A two-inch ball is 8 times as large as a one-inch ball ($2 \times 2 \times 2 = 8$). But if a one-inch ball is viewed from a distance of ten feet, it will be just large enough to hide a two-inch ball twice as far away, or a four-inch ball four times as far away.

Now, suppose that we have found the Moon to be 239,000 miles away. Let us get a ball 11 feet 5 inches in diameter, and place it in a conspicuous position on the top of a steep mountain. Having done so, let us measure off 1,262 feet (which is the one-millionth part of the Moon's distance), to a place where the ball will come between us and the rising or setting Moon. It will be found that the ball is just large enough, at that distance, to hide the Moon from us. Now, as the Moon is just a million times as far from us as the ball which hides it, it follows that its diameter is just a million times greater (11 feet 5 inches $\times$ 1,000,000 = 2,162 miles).

So far, so good. It is interesting to note that, in an eclipse of the Sun, the Moon acts the part of the ball just used. It so happens that, while the Sun's average distance from us (92,790,000 miles) is about 388 times that of the Moon (239,000 miles), his diameter (864,000 miles) exceeds hers (2,162 miles)

in about the same proportion. They therefore look as though they were about the same size, although the Sun's diameter is really almost 400 times as long, and his bulk is more than 60,000,000 times as great ($400 \times 400 \times 400 = 64,000,000$).

Most of the planets have no measurable diameter when seen by the naked eye, but by means of the telescope their dimensions also have been ascertained. The stars cannot be measured in this way, as they are so far off that they have no perceptible size, even when seen through the most powerful telescopes. The amount of light we receive from them is almost the only guide we have to their size, and even this is of no avail unless we know something of their distances from us.

WEIGHING THE PLANETS

One of the most astonishing things that astronomers have been able to do is to weigh the Sun and planets, so as to ascertain their *mass* or weight.[1] Yet the principle is as simple as that used in ascertaining their dimensions.

Get a light straight stick, and make a sharp point at each end of it. Then stick a potato on each point, and hang the apparatus from the ceiling by a string. Shift the string on the stick till the potatoes balance one another. Now give it a twirl and release it. The two potatoes will swing around the common centre of gravity, where the string is fastened to the stick.

If the two potatoes are of the same weight, the centre of gravity will be the same distance from each of them, and it will be found that each one swings around the other one in the same sized circle. But if one is heavier than the other, the centre of gravity will be nearer to the heavy one, and it will be found that the small one makes the largest circle. The apparatus, indeed, makes a primitive pair of scales with which the *relative* weight of each potato can be ascertained by noting the size of the circle it makes.

[1] These terms are not absolutely identical. The word *mass* refers to the amount of matter contained in anything, while *weight* has reference also to the force of gravitation, which varies in different worlds. The distinction is not important here.

Now the Earth and Moon form a similar weighing-machine. They are all the time swinging around their common centre of gravity, like our two potatoes, and their *relative* weights can be found by the same process.

But at the same time that the Earth and Moon are swinging around their common centre of gravity, the Earth-Moon family on the one hand, and the Sun on the other, are also swinging

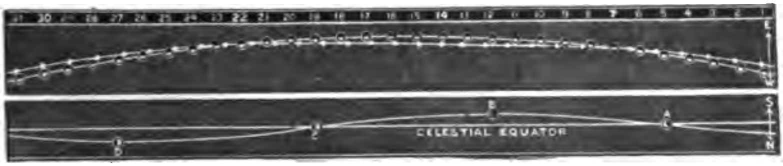


FIG. 16.—DAILY POSITIONS OF EARTH AND MOON
It will be seen that the lunar path is always concave towards the Sun.

around *their* common centre of gravity. In this case the Earth and Moon together are so small, in comparison with the Sun, that they are doing nearly all the swinging. Nevertheless the Sun is doing his part of the motion, even if it is too small to be easily perceived.

All the members of our Solar System (including even the Sun) swing around their various centres of gravity and influence one another in the same way, the amount of their influence depending on their *mass* and *distance*. The Sun outweighs all the planets 745 times, so that his part of the swinging is very small. Still it exists, and although it is convenient to say that the Moon swings around the Earth, and that the Earth swings around the Sun, it would be more correct to say that the Earth and Moon swing around their common centre of gravity, and that the Earth-Moon family and Sun do the same.

It will be seen that any family of worlds can be used as a weighing-machine, with which the relative weight of each individual can be ascertained by its influence over the other members of the family. Some of the stars, even, can be weighed against one another when they belong to one family.

ACTUAL WEIGHT

When we have found the *relative* masses or weights of the Sun and planets, we can, by finding the *actual* weight of one of them, in tons, find the actual weight of any, or all of them, in tons.

The readiest way of doing this is to weigh the Earth and find out how many tons of material it contains. Of course this is a very easy thing to do. All that appears to be necessary is to get a very strong weighing-machine, turn it upside down, so that the Earth rests in the pan, and then adjust the scale and read off the weight.

This last item must not be taken too seriously. The problem of weighing the Earth is really one of the most difficult tasks astronomers ever undertook. It has been solved, however, by several different methods,[1] and it is interesting to know that the Earth weighs about 6,600 millions of millions of millions of American tons (6,600,000,000,000,000,000,000). And the Sun contains 330,000 times that amount of material.

[1] The best plan is one which employs a torsion-balance to measure the mutual attraction of lead balls at known distances from one another. This is then compared with the observed attraction of the Earth for the same lead balls, which are known to be at a distance of about 4,000 miles from the centre of attraction. The mutual attraction of the balls being known, the law of gravitation shows how dense the World must be in order to give the balls their observed weight. (See Chapter XV for the key to this problem.)

CHAPTER IV

SOME PROBLEMS USED IN CELESTIAL MEASUREMENTS

"The methods used for measuring astronomical distances are in some applications absolutely the same as the methods of ordinary theodolite surveying, and are in other applications equivalent to them. . . . There is nothing in their principles which will present the smallest difficulty to a person who has attempted the common operation of plotting from angular measures." — *Sir George Airy.*

IN order that the beginner may better understand the principles upon which celestial measures depend, a few examples are given here, going further into details than in the preceding chapter. I do not undertake to say that everyone will be able to follow them all; but I have simplified them and explained the terms as much as possible, so as to help a non-mathematician who is willing to try.

DEGREES IN A CIRCLE

In trigonometry, which deals with the properties of three-sided figures, we (after the Greeks) divide the circumference of a circle into 360 *degrees of arc*, denoted thus (360°).

These degrees are indicated by straight lines radiating from the centre of the circle, which is supposed to be the point of observation.

Where two of these radiating lines enclose a square corner or *right-angle*, that angle evidently contains 90° of arc as measured off on the circumference.

Each degree is, for convenience, divided into 60 minutes (′), and each minute into 60 seconds (″) of arc. These minutes and seconds *of arc* have nothing whatever to do with minutes and seconds *of time*. It is a mere accident (and misfortune) that they are called by the same names.

Each line going from the centre to the circumference (like a spoke in a wheel) is termed a *radius* (plural *radii*).

RADII AND ARC OF CIRCLE

It has been found that when two radii are so placed that the central corner or *angle* contains 57° 17′ 45″ (= 206,265″), then the arc of circle cut off by the two radii is just equal in length to one radius.[1] Such an arc is termed a *radian*.

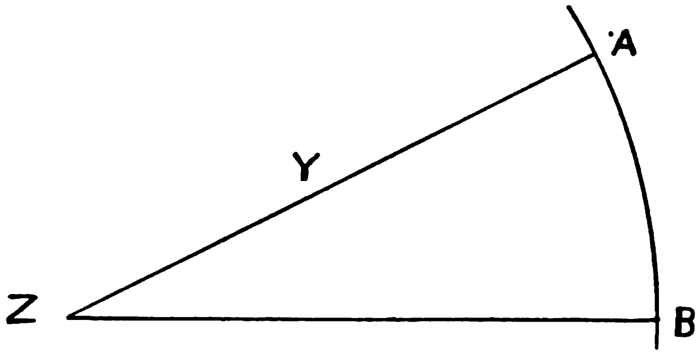


FIG. 17. — ARC OF CIRCLE

It naturally follows from this that when the angle is *half* of that just given then the arc cut off is just *half* as long as each radius (see Figure 17).

This is expressed as follows:

Let A B represent arc of circle
" *Z* " size of angle
" Y " radius of circle
" X " angle of 57° 17′ 45″
Then when Z = X, A B = Y
When $Z = \frac{1}{2}X$, $A\,B = \frac{1}{2}Y$
When $Z = \frac{1}{4}X$, $A\,B = \frac{1}{4}Y$
And so on.

[1] That is, the part of the tire which is cut off would be, if straightened out, just as long as one of the spokes.

The result is, that if we know the *distance* of an object in miles, we can tell its *diameter* in miles by measuring the angle enclosed by its opposite sides. For example, if an object 15 miles away is long enough to subtend an angle of 3° 49′ 11″ (=$\frac{1}{15}$ of X), then it must be about a mile long.

On the other hand, if we know the *diameter* of an object in miles, we can tell its *distance* from us in miles. For example, if we know that a certain object is a mile long, and we find by

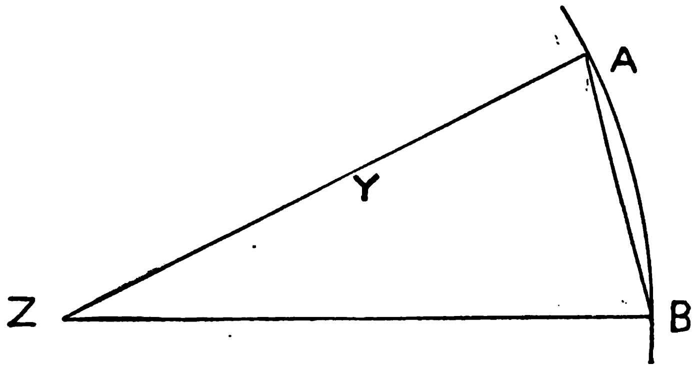


FIG. 18.—CHORD OF ARC

our instruments that it subtends an angle of 3° 49′ 11″ (=$\frac{1}{15}$ of X), then it must be about 15 miles away.

These two things can be ascertained; however, only when the distant object is near enough to have a measurable size when seen through a telescope.

THE CHORD OF AN ARC

For many purposes it is convenient to draw a straight line connecting the outer ends of the two radii. This line is called a *chord*, and the three straight lines together form what is known as a *triangle* (see Figure 18).

In such a triangle the two outside corners or angles, A and B, are equal to one another, and are each sharper or more *acute* than a right angle. This is true whether the centre angle Z be

great or small. In fact the greater the central angle is, the more acute become the outer angles. It is useful to remember that if the number of degrees in all the three angles of a triangle be added together, they are *always equal to* the number contained

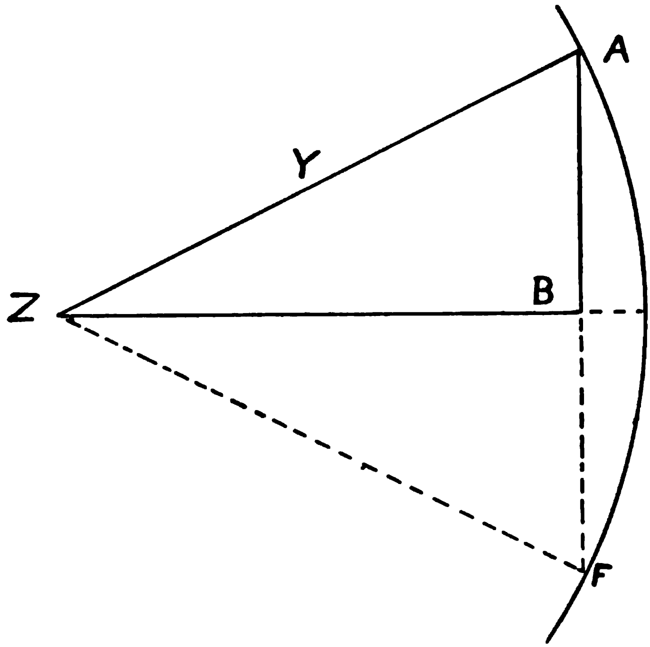


FIG. 19.—SINE OF ANGLE

in *two right angles.* That is, they always contain exactly 180° of arc.

The chord of an arc is of course shorter than the arc with which it begins and ends. The smaller the angle, the less difference there is between the two, and *in very small angles this difference can be neglected,* it is so minute.

The Greeks made great use of chords in their investigations. Ptolemy, the astronomer (*fl.* 127–151 A. D.), constructed tables

giving the length of both arcs and chords for every half-degree up to two right angles.

THE SINE OF AN ANGLE

The Hindus, however, simplified their problems by taking the chord of *double* the angle, and then cutting it in two and discarding one half. The half-chord used (A B) is known as a *sine* of the angle (A Z B) it measures (see Figure 19).

The advantage of a sine over a chord is this: In solving problems in trigonometry it is often convenient to have one of the outer angles a right angle, that is, one containing 90° of arc. Now, as the chord (A F) is cut in the middle by the bisecting radius (Z B), the two lines always cross at right angles (at B), and the resulting triangle (A B Z) is a right-angled one. The result of one of the angles being invariable is that part of the labour is saved, as the calculations are confined to the other two angles. All books on trigonometry have tables giving the length of sines, etc., for every degree and fraction of a degree.

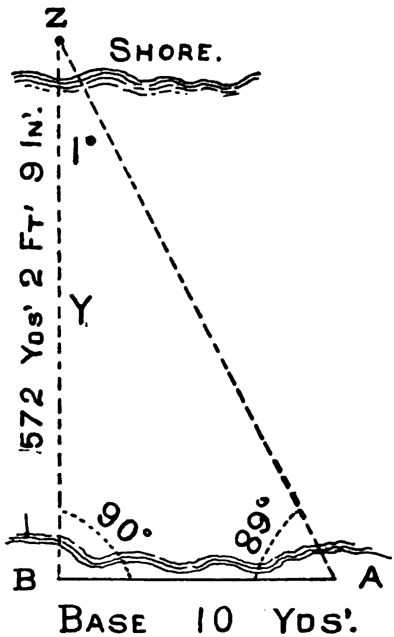


FIG. 20.—MEASURING WIDTH OF RIVER

MEASURING INACCESSIBLE DISTANCES

The advantage of a right-angled triangle is shown in the following problem, which is something similar to one given in the preceding chapter:

A surveyor wishes to measure the width of a river without crossing to the other side (see Figure 20).

First he measures off, on his own side of the river, a base-line (A B) 10 yards long. He stands at one end (B) of his base-line, and points his instrument at the other end of it (A). He then turns the instrument *one quarter round* (90° of arc), and selects an object (Z) on the opposite bank of the river. Having made a note of the number of degrees he has turned the instrument (90°), he goes over to the other end (A) of the base-line and repeats the operations. He will find that he will not have to turn his instrument so far around to make it point to the object selected (Z).

Let us suppose that he has to turn it only 89°. The two angles at the base will then together equal 179°. Now, as the three angles of a triangle, added together, always equal two right angles (180°), it is obvious that the opposite angle (Z) must be just 1°.

The problem then stands as follows:

As the sine of 1° (angle Z)
Is to the sine of 89° (angle A),
So is 10 yards (length of base A B)
To the perpendicular Z B (or Y).

After obtaining the length of the sines of 1° and 89° (which are given in all books on trigonometry), the problem is solved as follows:

As 01745 is to 99985, so is 10 yards to the answer, 573 yards, —

which is the width of the river as exactly as it can be found with five-place logarithms.

PARALLAX

The angle (Z) opposite the base of such a triangle is called by surveyors and astronomers the *parallax* of the distant object. The further off the object is, the smaller becomes its parallax.

The longer the base from which it is measured, the larger becomes the parallax.[1]

In the problem just considered it is obvious that if the object Z is exactly west of the observer at B, it will no longer be exactly west of him when he goes to A. It will be a little to the south of west. It is also obvious that the amount of its displacement will depend on its distance from him. The farther off the object is, the less it is displaced when he goes from one end of the base to the other. In other words, as stated before, the more distant the object is, the smaller becomes its parallax. If it is a very long way off, it may appear to be exactly west from both ends of the base-line. In this case it will be necessary to greatly lengthen the base-line in order to measure the distance of the object.

The word "parallax" is rather a hard one to remember. But astronomers can simplify matters when referring to the Sun's parallax by calling it the "mean equatorial long horizontal solar parallax." This is a useful thing to know.

A few examples of how astronomers utilize these principles will conclude this chapter, which some may consider to be dryer than a California summer, and more uninteresting than a Baedeker's guide-book to one who never travels.

MEASURING THE MOON'S DISTANCE

We will of course start with the problem of finding the Moon's distance from the Earth.

In Figure 21 the large circle represents a section of the Earth through the two poles of rotation. The small circle in the distance represents the Moon. B and L are the two stations at the ends of the measured base-line B L. We will imagine that they are 4,000 miles apart, and that they are both on the same meridian and at the same distance from the equator, which lies between them.

[1] "Parallax may be defined, generally, as the change produced in the apparent place of an object when it is viewed from a point other than that of reference." — ENCY. BRIT., *Parallax*.

Let us suppose that, to the observer at L, the Moon's centre is *exactly on the celestial equator*, and is therefore exactly 90° from the south pole (as well as from the north pole).

Then, to the observer at B, the Moon's centre will be found to be 57 minutes of arc (nearly 1°) *south of the equator*. That is to say, it will be only 89° 3′ from the south pole, of which the position is known even when it is out of sight. In the triangle B L M, therefore, the angles B and L lack 57′ of making two

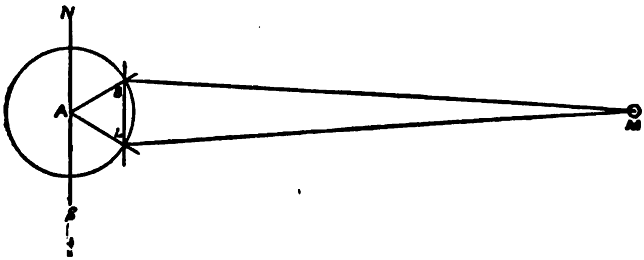


FIG. 21.—MEASURING DISTANCE OF MOON

right angles (180°). This 57′ is evidently the size of the other angle M.

We have now a problem absolutely identical in principle with the preceding one, which dealt with the width of a river. It stands as follows:

As the sine of 57′ (the angle M)
Is to the sine of 89° 3′ (the angle B),
So is 4,000 miles (the length of base B L)
To the perpendicular L M.

The problem is easily solved with almost the same figures as in that dealing with the width of the river.

As 01658 is to 99986, so is 4,000 miles to 240,000 miles,—

which is the approximate distance of the Moon at the time when the angles were measured.[1]

[1] The above problem has been simplified as much as possible, so that the principle may be readily grasped. As a matter of fact, the two ends of the base-line

For convenience of comparison, all results are reduced to fit a right-angled triangle having a base-line equal to the radius, or semi-diameter, of the Earth at the equator. The parallax is then known as the horizontal equatorial parallax.

The distances of Mars and Eros are measured in the same way as that of the Moon. But in the case of the Sun the results have to be obtained by taking advantage of a transit of

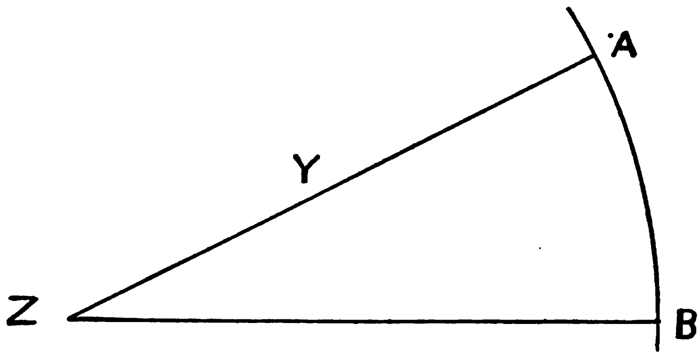


FIG. 22. — ARC OF CIRCLE

Venus, or by some other indirect method. The principles and results are, however, the same.

ARC PROBLEMS

The five following problems are worked out by means of two radii and the enclosed arc (see Figure 22). The observer is supposed to be at Z.

PROBLEM I. — Given the angular diameter of Sun or Moon, 32′ of arc (=1920″ of arc), as seen from the Earth, find their distances from us in terms of their own diameter A B (=1).

are never exactly on the same meridian. Nor are they ever exactly the same distance north and south of the equator. And the distance required is not from the Moon to the station L, but from the centre of the Moon to the centre of the Earth. Quite a number of corrections and precautions have to be taken to give trustworthy results. But they need not be given here. It is sufficient if the principle of the problem is thoroughly understood.

$$\frac{X}{Z}\,A\,B = Y. \quad \text{Therefore } \frac{206{,}265''}{1{,}920''}\,A\,B = 107\ A\,B.$$

[NOTE. — For meaning of letters see the table at page 40.]

So that the distances of the Sun and Moon from the Earth are both alike in terms of their diameters; that is to say, the distance of each one of them is 107 times as great as its actual diameter, whatever that may be.

This problem does not tell us how far they are from us or how large they are. It merely proves that if the Sun (or Moon) is a mile across, then it is 107 miles away from us; while if it is 1,000,000 miles across, then it is 107,000,000 miles away.

PROBLEM II. — Given the real distance of the Sun, 92,790,000 miles, and its angular diameter, 32′ of arc (= 1,920″), find its real diameter in miles.

$$\frac{Z}{X}\,Y = A\,B. \quad \text{Therefore } \frac{1{,}920}{206{,}265}\ \overset{\text{MILES}}{92{,}790{,}000} = \overset{\text{MILES}}{863{,}727}$$

The following form of this problem may perhaps be better understood:

As X is to Z, so is Y to A B.

Worked out, this is as follows:

$$\text{As } 206{,}265'' : 1{,}920'' :: \overset{\text{MILES}}{92{,}790{,}000} : \overset{\text{MILES}}{863{,}727}$$

PROBLEM III. — Given the real distance of the Moon, 239,000 miles, and its angular diameter, 31′ 6″ (= 1,866″), find its real diameter in miles.

This is a similar problem to the preceding one.

$$\frac{Z}{X}\,Y = A\,B. \quad \text{Therefore } \frac{1{,}866}{206{,}265}\ \overset{\text{MILES}}{239{,}000} = \overset{\text{MILES}}{2{,}162}$$

Or, by the "rule of three":

$$\text{As } 206{,}265'' : 1{,}866'' :: \overset{\text{MILES}}{239{,}000} : \overset{\text{MILES}}{2{,}162}$$

Problem IV. — Given the real diameter of the Sun, 863,727 miles, and its angular diameter 32′ (= 1,920″), find its real distance in miles.

It will be seen that this is the reverse of Problem II.

$$\frac{X}{Z} A\,B = Y. \quad \text{Therefore } \frac{206{,}265}{1{,}920}\ \overset{\text{miles}}{863{,}727} = \overset{\text{miles}}{92{,}790{,}000}$$

Or, as before:

$$\text{As } 1{,}920'' : 206{,}265'' :: \overset{\text{miles}}{863{,}727} : \overset{\text{miles}}{92{,}790{,}000}$$

Problem V. — Given the real diameter of the Moon, 2,162 miles, and its angular diameter, 31′ 6″ (= 1,866″), find its real distance in miles.

It will be seen that this is the reverse of Problem III. It is worked the same as Problem IV.

$$\frac{X}{Z} A\,B = Y. \quad \text{Therefore } \frac{206{,}265}{1{,}866}\ \overset{\text{miles}}{2{,}162} = \overset{\text{miles}}{239{,}000}$$

SINE PROBLEMS

The following problems are worked out by means of a right-angled triangle constructed of two radii and the sine (or half-chord) of the enclosed angle (see Figure 23; lettering same as before).

Problem VI. — Given the Sun's distance, 92,790,000 miles, and angular semi-diameter 16′ (= 960″), find its real semi-diameter in miles.

This is like Problem II, except that the semi-diameter is used instead of the diameter.

$$\frac{Z}{X} Y = A\,B. \quad \text{Therefore } \frac{960''}{206{,}265''}\ \overset{\text{miles}}{92{,}790{,}000} = \overset{\text{miles}}{431{,}863}$$

Problem VII. — Given the Moon's distance, 239,000 miles, and its angular semi-diameter, 15′ 33″ (= 933″), find its real semi-diameter in miles.

This is like Problem III, but uses the semi-diameter instead of the diameter.

$$\frac{Z}{X} Y = A\ B. \quad \text{Therefore } \frac{933''}{206{,}265''}\ \overset{\text{MILES}}{239{,}000} = \overset{\text{MILES}}{1{,}081}$$

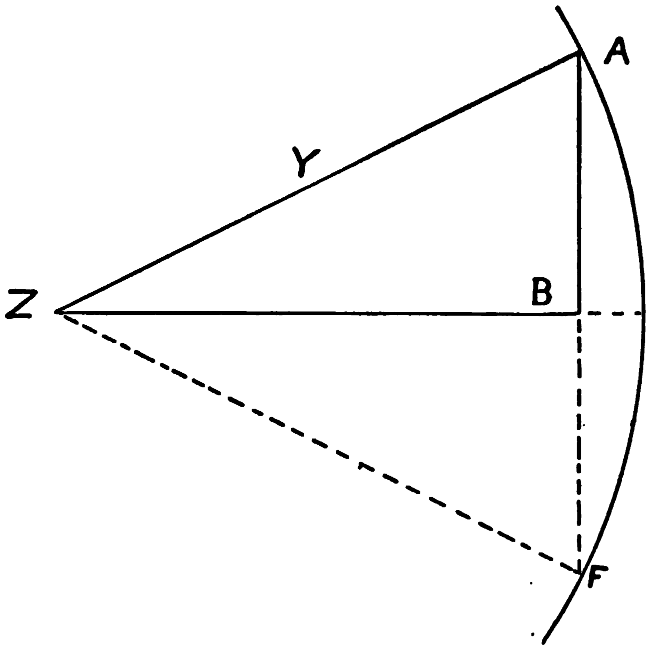


FIG. 23. — SINE OF ANGLE

In all the following problems the observers are supposed to be at A and B. Z is supposed to be the centre of the celestial body under observation.

PROBLEM VIII. — Given the Sun's parallax, 8.81″, and the Earth's semi-diameter, 3,963 miles, find the Sun's distance in miles.

All solar and planetary parallaxes are for convenience reduced to fit the semi-diameter of the Earth. This is here represented by A B, and the parallax by the opposite angle Z.

$$\frac{X}{Z}\text{ A B} = \text{Y. Therefore } \frac{206{,}265''}{8.81''}\ \overset{\text{MILES}}{3{,}963} = \overset{\text{MILES}}{92{,}790{,}000}$$

PROBLEM IX. — Given the Moon's parallax, 57′ (= 3,420″), and the Earth's semi-diameter, 3,963 miles, find the Moon's distance in miles.

This is a similar problem to the preceding one.

$$\frac{X}{Z}\text{ A B} = \text{Y. Therefore } \frac{206{,}265''}{3{,}420''}\ \overset{\text{MILES}}{3{,}963} = \overset{\text{MILES}}{239{,}000}$$

Here is the same problem worked by logarithms, which must be obtained from published tables of logarithms:

As the sine of 57′ (angle Z)	8.21958
Is to base 3,963 miles (A B)	3.59802
So is sine of 89° 3′ (angle A)	9.99994
	13.59796
	8.21958
To perpendicular (Z B)	5.37838 = 239,000 miles

[NOTE. — In small angles Z B = Y.]

PROBLEM X. — Given the Sun's distance, 92,790,000 miles, and the Earth's semi-diameter, 3,963 miles, find the Sun's parallax.

This is the reverse of Problem VIII.

$$\frac{\text{A B}}{\text{Y}}\text{ X} = \text{Z. Therefore } \frac{3{,}963}{92{,}790{,}000}\ 206{,}265'' = 8.81''$$

PROBLEM XI. — Given the Moon's distance, 239,000 miles, and the Earth's semi-diameter, 3,963 miles, find the Moon's parallax.

This is the reverse of Problem IX, and similar to Problem X.

$$\frac{A\ B}{Y} X = Z. \quad \text{Therefore } \frac{3{,}963}{239{,}000}\ 206{,}265'' = 57'$$

[If it is not too late, I would here suggest that those who do not like Mathematics would do well to "skip" the foregoing chapter.]

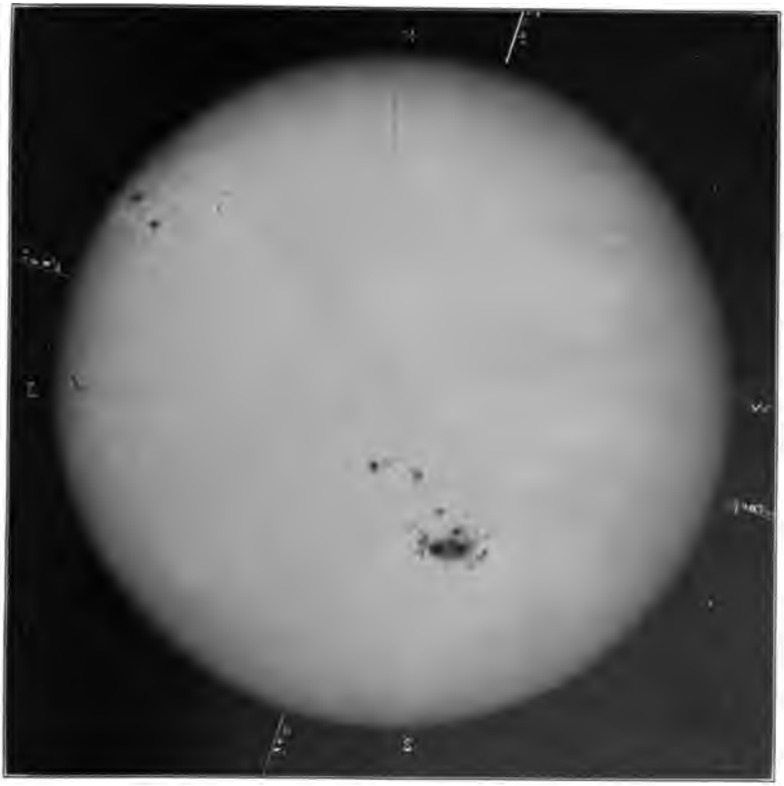


Fig. 24. — Sun, Showing Spots and Faculæ

Photographed at Greenwich Observatory, Feb. 13, 1892.

CHAPTER V

THE CHARIOT OF IMAGINATION

"Before their eyes in sudden view appear
The secrets of the hoary deep; a dark
Illimitable ocean, without bound,
Without dimension, where length, breadth, and height,
And time, and place, are lost."—*Milton*, "Paradise Lost," Book II.

"Oh Deep, whose very silence stuns!
Where Light is powerless to illume,
Lost in immensities of gloom,
That dwarf to motes the flaring suns!"
—*G. Sterling*, "The Testimony of the Suns."

A LONG JOURNEY

TO enable us to realise, to some extent, what position man holds with reference to the Universe, let us leave our Earth for a short time, and hasten away, in the Chariot of Imagination, to a point in space half-way between our Sun and Alpha Centauri, the nearest of the other stars.

We will take with us a specially constructed chronometer, made to indicate long periods of time; a special cyclometer, made to fit the wheels of our chariot; and a number of other scientific instruments which may prove useful in our celestial researches.

In order that we may not get lost or have any corners to turn, we make our start from Cape Town, South Africa, in the night-time, when the Moon is above the horizon and Alpha Centauri is on the meridian.

As this may be the first time some of us have travelled through space unaccompanied by Mother Earth, it will be well for us to travel slowly, so that we can get a good view of our surroundings, and at the same time avoid running into unnecessary danger. We will therefore keep a firm hand on the lines, from the start,

so as to prevent our imaginary steeds from running away with us. On such a long journey the most satisfactory speed for us to keep up will perhaps be that at which light travels, about 186,000 miles per second.

Everything being ready for our trip, the signal is given. "*One, two, three. Away we go!*"

Before the words are fairly uttered, we find ourselves at the Moon's distance and in the bright sunshine. By a curious optical delusion we did not seem to move when the word was given, but the moonlit Earth suddenly dropped from beneath our feet. For a fraction of a second it appeared to swell, as distant lands and moonlit seas sprang above the horizon. Then the Sun rose with a jerk, and the crescent Earth began to shrink in size as its distance increased.[1]

At the end of one minute the Earth is still plainly visible in the bright sunlight, but the Moon is almost out of sight. In five minutes nothing is to be seen of either of them.

For a time we are in the sunshine, but the light soon begins to wane as we recede from the Sun and approach the confines of the Solar System.

In four hours we are at the distance of Neptune, and the Sun is not much more than a very brilliant star in the gathering twilight.

Although the Sun continues to dwindle in size as we leave it behind, it shines continuously, there being no horizon to hide it from us. After we have been a month on our journey, as shown by our chronometer, it is practically nothing but a bright star among the multitude of stars by which we are entirely surrounded.

By this time we have discovered that we have left behind many things which seemed very real and important while we remained on *terra firma*.

There is now no north or south, no up or down. The star-

[1] For the above effects to be produced, we should really have to travel slower than light, otherwise nothing would be visible in our rear. Every impossible illustration has its discrepancies, as Artemus Ward would say.

sphere has ceased to turn on its axis, so that there are no pole stars. The wandering planets have long since disappeared. There is no Sun or Moon. Day and night have ceased to roll. Seed-time and harvest come no more. Summer and winter are meaningless terms. Aside from our chronometer, months, years, and centuries have now no significance. Away from our Earth, geological periods trouble the mind no more.

We keep on in a straight line, at the same speed, for *two long years*, as registered by our chronometer. The star which used to be our Sun is now directly behind us, but has long ceased to be conspicuous for either size or brilliancy.

And now the special cyclometer which we brought along tells us that we are at last nearing our goal, the half-way house between the centre of our system and the nearest outside star.

AMONG THE STARS

Arrived at our lonely destination, let us check our imaginary horses, hitch them to an imaginary post, and take a survey of our actual surroundings.

As we did not bring our Earth along with us, our view is not impeded in a downward direction. We can see clearly below and around, as well as above.

What is there to be seen from our point of vantage?

One of the first things to attract our attention is that we do not appear to have any immediate surroundings. We are *solitary in empty space.*

Instead of being surrounded by houses and trees lighted up by the dazzling glare of a hot Sun, or half-revealed by the soft glamour of a pale Moon, we find ourselves *alone in the midst of perpetual starlight,* which no Sun or Moon ever interferes with.

There is no cloud or fog, for all is cold, clear, still, dark, and apparently void.

But in the far distance there are plenty of objects to make up for an unoccupied "fore-space."

The "back-space" of sky is all more or less crowded with stars. To the naked eye there are about 6,000 visible. These

are distributed promiscuously in irregular clusters and haphazard groups, without any regard to pattern or symmetry.

But besides these groups of stars there are, in some parts of the sky, great irregular streaks of nebulous haze. One set of these hazy streaks is so long-drawn-out that its snake-like folds and spirals almost form a girdle around us.

The unaided eye cannot pierce this haze, and without further insight even the imagination itself is unable to invent a reasonable explanation of this "Milky Way."

THE EYES OF SCIENCE

Let us now imagine that our eyes improve in light-grasping power till they equal the most powerful telescopes in existence. What is there *now* to be seen from our point of vantage?

The result is something startling — astounding — overwhelming. The scene is grand beyond the power of language to describe — magnificent beyond the ability of the mind to conceive.

The Earth we came from is still invisible — lost in the depths of infinite space.

The Sun that ruled our Solar System with such undisputed sway is visible still, but it rules no more. It was a SUN that reigned supreme among a thousand little twinkling stars. It is now but a star among *a hundred million* fellow-stars.

But though we have lost our Earth and its Sun, we have gained more than we have lost. For we have revealed before us a goodly portion of the Universe itself. And though we see no more a panoramic succession of days and nights, seasons and years, we do not miss these *earthly phenomena*. For in their stead we see the stately evolutions of countless squadrons of heavenly orbs, circling through never-ending time in an ocean of limitless space.

We have here no need of the Sun, neither of the Moon; for the everlasting glory of the *Great Cosmos* enlightens us, and the iridescent mantle of Universal Nature enfolds us.

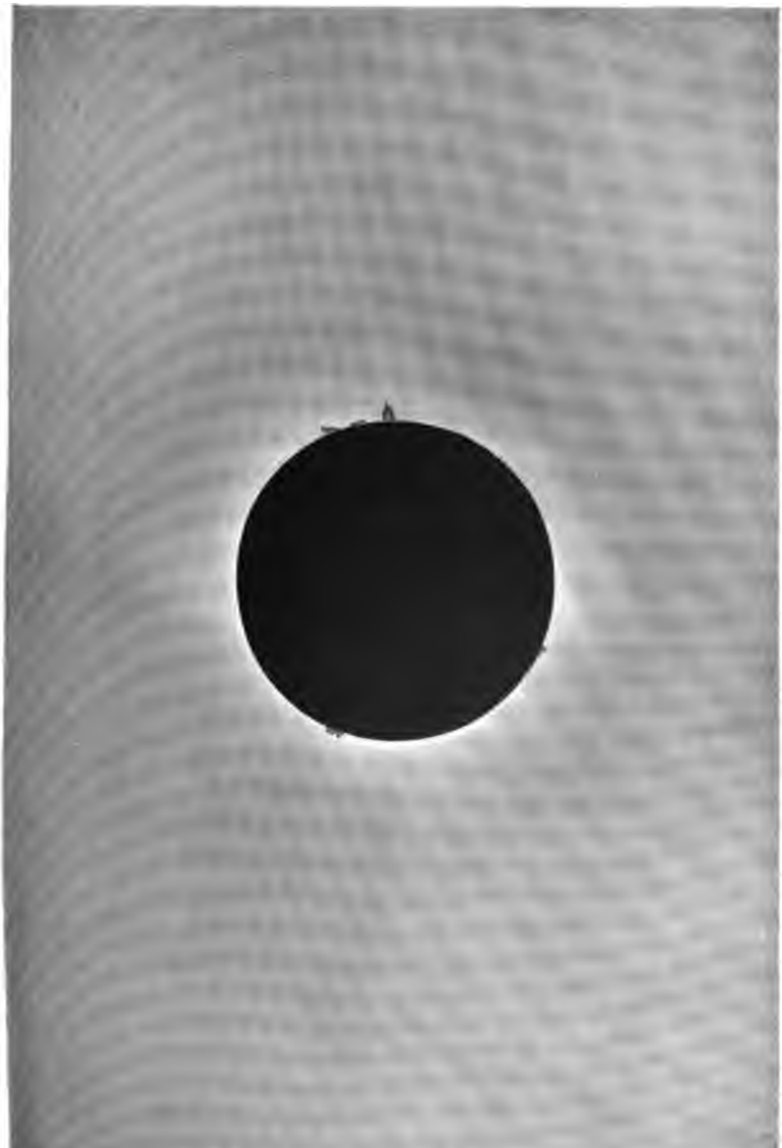


Fig. 26. — Solar Flames and Corona, as Seen during Eclipse of May 28, 1900

By Burckhardt. (*From Comstock's "Text-book of Astronomy," published by Messrs. D. Appleton & Co.*)

On every side, above and below, we see stars by the million. They are strewn through endless space like the blinding snow-flakes of a Western blizzard. They are as thick as the leaves of an earthly forest.

And we know that each and every star is a SUN, more or less like unto our Sun. Many, if not all of them, have subject worlds revolving around them like the planets which compose our own system.

Gazing on such a picture, words are not equal to express our sense of littleness. As the poet says:

> This is a wondrous sight,
> And mocks all human grandeur."

Contemplating the star-strewn heavens, the deist may well exclaim with one of old —

> "When I contemplate the heavens,
> The work of thy hands,
> The Moon and the stars,
> That thou hast disposed,
> What is Man,
> That thou shouldst remember him,
> The Son of Man,
> That thou shouldst watch over him?"
>
> — *Ps.* viii, 3 (Ségond and Diodati).

The poet Shelley has beautifully described such a scene. He says:

> "Below lay stretched the Universe.
> There, far as the remotest line
> That bounds imagination's flight
> Countless and unending orbs
> In mazy motion intermingled,
> Yet each fulfilled immutably
> Eternal Nature's law.
> Above, below, around,
> The circling systems formed
> A wilderness of harmony;
> Each with undeviating aim,
> In eloquent silence, through the depths of space,
> Pursued its wondrous way."

All around us is —

— "the abyss of an immense concave,
Radiant with million constellations, tinged
With shades of infinite colour."

A RUSH THROUGH SPACE

After having gazed for a while at the wonderful scene around us, — a scene so magnificent that even the words of a Saul among the poets fail to give any adequate conception of it, — we unhitch our imaginary horses from our imaginary post, turn our Chariot of Imagination toward one of the stars, and rapidly approach it.

ONLY A STAR

The star we selected for examination was a very ordinary-looking star. It was far smaller than many of its neighbours, and did not shine anything like so brightly as some of them.

But now that we have arrived in its vicinity it has grown in size and brilliancy till all the other stars have either gone out of sight or become faint dots of light, just perceptible in the growing daylight. It has, indeed, become so overwhelmingly radiant that we have to put on dark spectacles to enable us to use our eyes without being blinded.

Let us stop and watch this star for a thousand years or so, and see what changes are going on around it as it drifts along in the ocean of space.

The star itself is a round yellowish-white ball more than 800,000 miles in diameter. Its glowing surface, or *photosphere*, is one vast mass of shining cloud, which has the appearance of being dotted all over with still brighter specks, like rice-grains. This cloud-like photosphere is composed of calcium and other elements, kept in a white-hot state by an unimaginably intense heat rising from the gaseous interior of the star. The white photosphere radiates into outer space about four times as much

Fig. 25. — Group of Sunspots

Photographed with the Greenwich 26-inch Refractor, on Sept. 11, 1898. The largest nucleus was about 24,000 miles long.

Fig. 27. — Eruptive Prominences

Eclipse of May 28, 1900 (Barnard and Ritchey). The largest of these "hydrogen flames" is 60,000 miles high.

light and heat as an electric arc-light of the same size would do.[1]

There are some peculiar features about this star as seen from a short distance. Physical and mechanical reactions of inconceivable violence are taking place beneath its surface. In some places they give rise to what look like volcanic eruptions on a vast and awe-inspiring scale. To an outside observer these centres of eruption appear like great irregular black blotches scattered about the white cloud-like photosphere. They are surrounded by plume-like shadows or penumbræ. By watching these black spots we soon find that the star is spinning slowly around on its axis, completing a revolution in about twenty-seven of our days.

The light given out by this white photosphere is so dazzling that little more can be made out, even with dark glasses. We will therefore use special instruments to turn it aside, so as to enable us to see more clearly what other phenomena are going on in the neighbourhood.

We can now see that the entire body of the star is buried under a shoreless ocean of transparent fire of a scarlet hue. This fiery ocean, or atmosphere, is everywhere from 4,000 to 5,000 miles deep, and appears to rest on the white cloud-like photosphere already described. The storm-tossed surface of this fiery ocean bristles at every point with huge ascending "flames" of the same scarlet colour. Those on our side of the star are not readily examined, on account of the brilliancy of the photosphere, but those around the edges are plainly visible with proper apparatus. Most of them are about 8,000 or 10,000 miles high, but here and there are larger ones, reaching up 60,000 miles or more. These huge ruddy flames assume a great variety of forms. They resemble jets of steam, fireworks, fountains, ocean breakers, cyclones, torpedo explosions, and volcanic eruptions, all on a scale of inconceivable magnitude.

[1] By the way, an electric arc-light the size of a pin's head cannot be examined without the aid of dark glasses, it is so overwhelmingly bright. And its temperature is 6,300° F. But this star is nearly a million miles through and is very much brighter and hotter!

As we watch this stormy scene it reminds us of a wind-tossed prairie fire as seen by night through a telescope on our little Earth. The flames rise and dart forward, fall back and roll over; bend, twist, and curl; embrace, wrestle, and fling themselves apart. Before our eyes they change into all imaginable shapes, so that we find it almost impossible to realise their overwhelming magnitudes and the terrific speed of their varied movements. Every once in a while we see great ruddy blasts of fiery gas rise from the surface with tremendous force and inconceivable velocity. Some of these flaming jets shoot up at the rate of 250 miles in a second of time, and reach an altitude of 200,000 or 300,000 miles. They then branch out in tree-like clouds, and finally break up and scatter in a shower of solar fireworks. The very largest of these flames are long enough to be wrapped sixteen times around our Earth.

These ruddy flames (though cooler than the white photosphere beneath them) are so inconceivably hot that they do not burn. In fact they would "unburn" any burnt substance which might fall into them, even if it should happen to be as large and heavy as our Earth. No chemical compound could exist for a second in such a terrific heat. No element, even, could remain there in a solid or liquid state. The flames are composed of incandescent hydrogen and helium, while the ruddy sea from which they rise contains also iron, magnesium, sodium, and other metals, all vaporised by the tremendous heat.

This scarlet ocean of fiery gas is termed a *sierra* or *chromosphere.* The flames which rise from it are known as *prominences.*

Outside of all these is a *corona*, consisting of great hazy radiating streaks of some light and apparently gaseous substance, extending a million miles or more into outer space. Owing to their distribution, and to the fact that the star is spinning around on its axis, these "repulsive" streaks are not straight, but slightly curved, and have a very peculiar plume-like appearance.

FIG. 28. — SOLAR CORONA. ECLIPSE OF MAY 28, 1900

Photographed by Chabot-Dolbeer Eclipse Expedition.

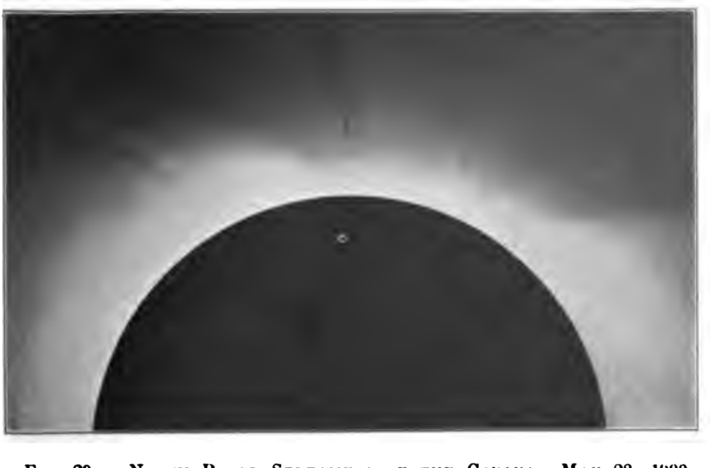


FIG. 29. — NORTH POLAR STREAMERS OF THE CORONA. MAY 28, 1900

Crocker Eclipse Expedition.

OFFSPRING OF A STAR

As we watch the eruptive "freckles" which come and go every eleven years on the surface of the star, we notice a number of small balls sweeping around and around it, all going in the same general direction. These are all *worlds,* more or less like the one on which we used to live before we began our heavenly wanderings. Let us watch them as they eddy around the star, like moths circling around a lantern in the dark.

THREE CLASSES OF WORLDS

The most noticeable of them are four outer or *superior* planets. These are so much larger and more powerful than the rest that they form a kind of *aristocracy,* subject only to the reigning monarch in the centre. They do not appear to shine by their own light, yet they are still puffed up with heat. They have followers, or *satellites,* of their own, so that they are something like petty rulers subject to a higher power.

Four very insignificant planets form an inner or *inferior* family of worlds. They give out neither light nor heat of their own, so they may be called *terrestrial* planets. They are much more under the control of the central ruler, but at the same time may be said to bask in the sunshine of his favour. They are, in fact, the *bourgeoisie* or well-to-do citizens of the monarchy.

Between these two families of worlds there is a whole regiment of almost invisible planets, which may be called *asteroids,* from their small size and star-like appearance. They are the *proletarians,* the working-class of the monarchy, subject not only to the legitimate rule of the sovereign, but also to the overbearing authority of the aristocracy on the one hand, and to the petty bossing of the bourgeoisie on the other. They are in fact "between the upper and the nether millstone." The result is shown by the steep, elongated, and apparently dangerous paths some of them are compelled to follow, with neither hope of relief nor promise of reward.

Although the four outer planets appear to us to be very large, yet they are extremely small compared with the central star, which is 560 times as large and 745 times as heavy as all the planets put together.

Let us now examine some of the individuals composing these three classes of worlds, beginning with the inner planets.

THE INNER PLANETS

The one which is nearest to the central star is small, and very little can be seen of it. The second is larger, with a dense atmosphere which somewhat obscures the planet itself. Both of these little worlds move at a speed many times greater than that of a cannon-ball, yet it takes them several months to go once around the central star.

PLANET NUMBER THREE

Planet No. 3 is slightly larger than No. 2, its diameter being nearly 8,000 miles. It is, indeed, the largest of the inner family of worlds. It is more than 90,000,000 miles from the star around which it is sweeping. It takes just a year to complete a revolution, although it travels at the astounding rate of *eighteen miles in a second of time.*

On looking more closely at this world, another and smaller planet is seen buzzing around and around it. This is a moon or satellite, which goes around its primary in the same direction as that is going around the central star. It is a little over 2,000 miles thick, so that the principal planet is about fifty times as large as its companion.

A more attentive look at No. 3 reveals several peculiarities. It is spinning around like a top, turning in the same general direction as that in which it goes around the central star. The two points which form its poles of rotation are white, as though covered with ice and snow. Its surface is variegated, and is evidently composed of land and water. There are continents, oceans, islands, seas, lakes, rivers, and mountains. The land appears to be more or less covered by vegetation of a green

Fig. 30. — Mercury, the First Planet
By Schiaparelli. (*From Todd's "Stars and Telescopes," published by Messrs. Little, Brown, & Co.*)

Fig. 31. — Venus, the Second Planet
By Antoniadi. (*From Comstock's "Text-book of Astronomy," published by Messrs. D. Appleton & Co.*)

Fig. 33. — Mars, the Fourth Planet
By Knobel. (*From Todd's "Stars and Telescopes," published by Messrs. Little, Brown, & Co.*)

colour, while portions of the surface are hidden by drifting clouds. Altogether, it looks like a world which might be inhabited. Although small compared with the giant planets which circle on the outskirts of the system, yet the diversity of its surface, and the terrific speed with which it circles around

FIG. 32. — TERRA, THE THIRD PLANET, AND ITS SATELLITE OR MOON

the central star, entitle it to the archangel's song as given in the prologue to Goethe's "Faust":

"And swift and swift beyond conceiving,
The splendour of the World goes round,
Day's Eden-brightness still relieving
The awful night's intense profound.
The ocean tides in foam are breaking,
Against the rock's deep bases hurled,
And both, the spheric race partaking,
Eternal, swift, are onward whirled."
— *Bayard Taylor's Translation.*

PLANET NUMBER FOUR

Planet No. 4 has a ruddy appearance. It is considerably smaller than the one just described, its diameter being only about 4,000 miles. It has two very small moons circling around it. Like No. 3, it has the appearance of being in a condition suitable for sustaining life. It appears to have an atmosphere, clouds, and variegated continents. Its poles, too, are white, as though covered by ice and snow.

PLANETOIDS

After Planet No. 4 there is a great crowd of little worlds which are too small to be of much importance. The most interesting thing about them is the speculation whether or not they are the fragments of two larger planets that have unsuccessfully tried to occupy the same space at the same time.

Fig. 34. — Relative Sizes of Earth and Mars

A GIANT PLANET

Outside this swarm of pigmy worlds there circles and spins a gigantic ball about 1,200 times the size of Planet No. 3. It is not only the largest of all the planets, but is larger than all the rest of them put together. It has a dense impenetrable atmosphere, with bands of clouds around its equatorial regions. There are five moons sweeping around it, some of them being of considerable size, far larger than any of the planetoids just mentioned. The main planet, although so large, spins around in a little less than ten hours. This rapid rotation has made its equator bulge out, so that the cloud-like surface of the planet is something the shape of an orange.

A RINGED PLANET

After this there is another big globe, only second in size to the one just described. But this one is surrounded by such an

Fig. 35. — The Zone of Asteroids between Mars and Jupiter

Fig. 36. — Jupiter, the Largest Planet

Showing great red spot and transit of satellite. Lick Observatory.

astonishing arrangement that one cannot help rubbing his eyes to see if they have not deceived him. It looks as though there was a large round thin disc, with a good-sized round hole in the middle. In the centre of this hole is the planet itself, not quite large enough to fill the hole, and not visibly connected with the disc. On a closer view the disc is seen to have a series of gaps and thin places in it, extending all around, as though it were really a series of discs all lying in the same plane, and having the planet for a centre, but differing in size and texture. If these concentric discs or rings were visibly supported by the planet, they would not seem so extraordinary, but the closest scrutiny fails to discover any physical connection with the globe they surround. The only explanation that seems able to account for their continued existence is that they are composed of countless millions of tiny satellites crowded together, and revolving around the planet in the same direction.[1]

FIG. 37. — RELATIVE SIZES OF JUPITER AND EARTH

Farther off than these rings there are nine satellites, or moons, revolving at different distances from the planet. The whole family group seems almost a miniature of the solar system of which it forms a part, with a hint thrown in as to how that system originated.

[1] If they were farther from the planet, they would probably coalesce into regular satellites, but as it is, the tidal action of the huge planet prevents this.

TWO OUTER PLANETS

There are two more large planets outside the one just described. But they are not so remarkable in appearance, and they are so far from the central star that they are comparatively in the cold and dark. The outside one is about 30 times as far off as Planet No. 3, and is 125 times as large. It moves only a little over three miles in a second of time, and, as it has a large circuit to make, it takes 164 years to go once around the central star.

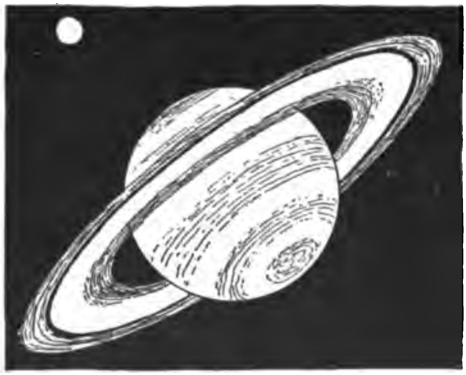


FIG. 39. — RELATIVE SIZES OF SATURN AND EARTH

It is interesting to note that the combined mass of the four outside planets just mentioned is about 220 times as great as the combined mass of the four inner planets, with all the visible planetoids thrown in. Also that the same outside planets together weigh 450 times as much as No. 3 alone. If only bulk and mass were concerned, it would scarcely be worth while to mention the inner planets at all, they are so insignificant.

SOLAR SYSTEM No. 3,141,592,653

It is hardly necessary to explain that the star we have been examining, with its attendant worlds, forms *our own Solar System.* The insignificant little globe which I have called "Planet No. 3" is *our own World,* once regarded, by its reasoning inhabitants, as the whole Universe, with nothing outside but the *Realms of Chaos.*

If we were to approach any one of the millions upon millions of sovereign suns revealed by the telescope, we should in all

Fig. 38. — Saturn, the Ringed Planet

Photographed at Yerkes Observatory.

probability find it to be the centre of a family group more or less similar to ours. Some systems are smaller, but others are far larger, while many are more elaborate and democratic, with two, three, four, a hundred, or a thousand suns circling around their common centre of gravity.

Fig. 40. — Relative Sizes of Neptune and Earth

CHAPTER VI

DIMENSIONS OF THE UNIVERSE

"Firstly, we may inquire as to the extent of the Universe of stars. Are the latter scattered through infinite space, so that those we see are merely that portion of an infinite collection which happens to be within reach of our telescopes, or are all the stars contained within a certain limited space?"

—*Prof. Simon Newcomb.*

PLANETARY DISTANCES

IN the third and fourth chapters I tried to show the principles by which the distances of the heavenly bodies are measured. It was there stated that the Moon's distance from us is about 239,000 miles, and that the Sun is about 388 times as far off. The most reliable measurements make the Earth's distance from the Sun 92,790,000 miles. Neptune, the farthest planet in our system, is about 30 times as far from the Sun as we are, so that it is 2,790,000,000 miles away.

This distance is so tremendous that it is unthinkable. The mind of man cannot grasp it. It is as utterly beyond our comprehension as infinity itself. Yet when we turn to the stars we find that this vast distance is as nothing when compared to the intervals separating one star from another.

STELLAR DISTANCES

It has been ascertained that the nearest star outside our system is something like 9,000 times as far off as Neptune, whose distance seemed so amazingly great. Alpha Centauri, the nearest of all the stars, is distant from us about 25,000,000,000,000 miles. Its light, travelling at the rate of 186,000 miles in a second of time, takes more than four years to come to us.

The brightest star in all the sky is known as *Sirius*, or the Dog Star. It is twice as far from us as Alpha Centauri, and is therefore more than eight "light-years" away.

The distances of about sixty other stars, ranging up to sixty light-years, have been more or less approximately ascertained. All the others are too far off for our sounding-rods. They are out of reach in the depths of space. All that we know for certain concerning their distances is that none of them are less than 4,000,000 times as far from us as our Sun, which is nearly 93,000,000 miles away.[1]

COMPARISONS

Now it is very easy to say that the nearest star outside our system is 25,000,000,000,000 miles away, but it is not so easy to realise what that distance is like. Let us try to do so by means of some simple illustrations.

In the first place it is necessary to realise the proportionate distances and dimensions of the members of our own Solar System.

If we take a *one-inch ball* to represent our Earth, it will require a *nine-foot globe* to represent the Sun.

Let us place this nine-foot globe on a level plain that has just had the grass burnt off it, and set up wire circles (on posts) to indicate the various planetary orbits.

The sizes of the planets and the distances of their orbits from the central globe will be as follows:

Planet	Size	Distance
Mercury . . .	large pea . . .	127 yards
Venus . . .	one-inch ball .	235 "
Earth . . .	one-inch ball .	325 "
Mars . . .	half-inch marble .	495 "
Asteroids . .	small seeds	{ 676 " 1,385 "
Jupiter . . .	eleven-inch globe	1 mile (nearly)
Saturn . . .	nine-inch globe .	1¾ miles
Uranus . . .	four-inch globe .	3½ "
Neptune . . .	five-inch globe .	5½ "

[1] Investigations are now in progress which promise greatly to extend the list of stars having a measurable parallax. It is possible that the distances of most of the naked-eye stars will be ascertained before many years have passed.

On this scale our Moon will be represented by a pea moving in a circle at a distance of 30 inches from the one-inch ball representing the Earth.

The outside ring of Saturn will be 21 inches in diameter.

The orbit of Neptune will be 11 miles across, and will take nearly 35 miles of wire to mark it out.

Let us now make arrangements with an electric light company to cover our nine-foot globe with a complete network of electric lights, so close and compact that every part of the surface will give off more light and heat than the brightest part of an arc-light. We will then choose a dark yet clear night, and turn on the current.

We shall find that all of our toy planets are more or less brilliantly illuminated *on one side* by the central light. But of course the outer side of each "planet" will be dark and invisible. Let us station ourselves just beneath the one-inch ball which represents our Earth, and take a look around at our miniature "solar system."

The overpowering effulgence of the nine-foot globe, 325 yards away, makes it necessary for us to put up a shelter to protect us from the light and heat.

Apart from our electric "sun," the most prominent object visible from our position will be the quarter-inch ball which goes around us at a distance of 30 inches. It will, in fact, look as large as our nine-foot "sun," but will not be anything like as bright.

As the illuminated side of this imitation "moon" does not always face us, it will show all the phases of the real Moon as it goes around in its little orbit.

The first of our toy planets (that is, the one nearest to the central globe) will be just visible to us when most favourably placed. The second will shine very brightly when it is at a large angle from our "sun." Both of these toy planets will show lunar phases if examined with the help of a telescope.

The fourth "planet" (half an inch in diameter), will also be very brilliant when at its nearest, 170 yards away. But at other times it will be rather inconspicuous.

Fig. 41. — Lick Observatory on Mount Hamilton, California

Fig. 42. — Main Entrance and Great Dome, Lick Observatory

The first and second of the large planets will also be tolerably conspicuous, although a telescope will be necessary to show details.

The two outside planets will not be visible at all without a telescope. The farthest of them will not vary much in appearance; its distance at all parts of its orbit being something like 5½ miles away from us.

The nearest star will, on the same scale, be represented by an electric globe, probably 12 feet across, at a distance of about *50,000 miles.* Sirius will take a similar globe, nearly 30 feet in diameter, about *100,000 miles away.* The largest star visible to us may probably be represented by a 100-foot globe, somewhere about 1,000,000 miles distant.

This illustration gives a fair idea of the comparative dimensions and distances of the principal bodies forming our Solar System, but fails to convey any definite idea of stellar distances. Let us try some other illustrations.

A LOCOMOTIVE

We all know what it is to travel at the rate of 60 miles an hour. At this rate it would take 17½ days and nights to travel around our own world.

To reach the Moon, travelling at the same rate, it would take 166 days, or nearly half a year.

To reach the Sun, we should have to travel for 176 years.

To go around the Sun would take about 5 years.

To go from the Sun to Neptune, the farthest planet, would take 5,000 years, and the railway fare, at one cent a mile, would be nearly $28,000,000. This makes a railroad impracticable.

A CANNON-BALL

Now take a cannon-ball travelling at the rate of a mile in five seconds.

It would go around the Earth in 36 hours, and would reach the Moon in 14 days.

To get to the Sun would take it 15 years, and it would require 5 months to go around it. To go from the Sun to Neptune, the farthest planet, it would have to travel at the same speed for 415 years.

AN ARROW OF LIGHT

A wave of light travels at the enormous velocity of 186,000 miles in one second of time. So it would go around our Earth more than seven times in a second. It would reach the Moon in a second and a quarter.

It takes more than eight minutes for the Sun's light to reach us, and over four hours for it to get to Neptune, the outside planet in our own system.

At the same rate, 186,000 miles a second, it takes more than four years for the light of the nearest star to reach us.

Sirius, the brightest star in the sky, is so far off that the light which reaches us to-night has been eight and a half years on the way. If it were to collide with another star now, we should not see the flare-up for eight years and a half.[1]

A PILE OF PAPER

Now, suppose that we had here a pile of thin paper, with as many sheets in it as there are miles between us and the nearest star. What would be the height of the pile, supposing that it took 200 sheets to measure one inch in thickness?

Those people who are naturally reasonable in their ideas and moderate in their estimates might think that the pile would probably be a hundred feet or so in thickness. Others, who are naturally wild in their ideas and extravagant in their guesses, would think that the pile might possibly be a mile thick. As a matter of fact, it would reach up nearly *2,000,000 miles*. More exactly, its height would be *1,972,853 miles, 942 yards, and 8 inches*.

[1] The distance of Sirius is not less than that stated, but there is a possibility that it is greater.

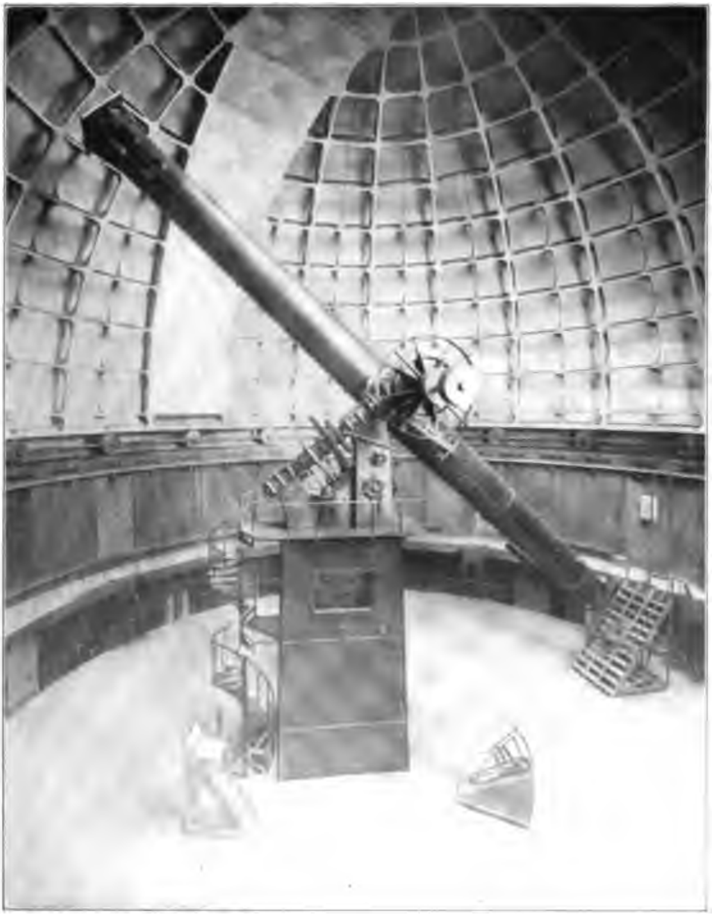


FIG. 43. — THE THIRTY-SIX-INCH REFRACTOR AT LICK OBSERVATORY

The tube is 56 feet long and weighs several tons. It is equatorially mounted, with a driving clock. The entire floor under the dome can be raised or lowered 26 feet. It is shown half-way down.

As this pile of paper is rather top-heavy, suppose we lay it down on its side. Then it will go nearly 79 times round the Earth. Yet every inch in this great pile of paper represents a distance of 200 miles. The sheets would have to be placed a mile apart before they would reach to the nearest star.

A STACK OF BLOOD DISCS

Perhaps a smaller illustration of the same kind may be more within our mental grasp.

Human blood is an almost colourless fluid, crowded with very small red discs or corpuscles. These discs are flat and coin-shaped. They are so extremely minute that if they were piled up one on the top of another, like a stack of coins, it would take 15,000 of them to reach one inch in height.

If we let each disc stand for one mile, then the height of the pile representing the Moon's distance will be 16 inches. That representing the Sun's distance will reach up 172 yards, and Neptune's pile will be nearly three miles high. But the pile which contains as many discs as there are miles between us and the nearest star will be 26,000 miles in height. If it were laid down on the ground it would go around the world.

VIOLET WAVES

The shortest light-waves which affect the eye are those which produce the sensation of violet light. It takes 61,000 of these waves to measure one inch. If a single wave stands for a mile, then the distance of the Moon will be represented by 4 inches; of the Sun, by 42 yards; of Neptune, by 1,250 yards; and of Alpha Centauri, by 6,400 miles.

Then we must remember that the vast majority of even naked-eye stars are hundreds and thousands of times farther off than the one we have been considering.

A LONG STRAND

The cotton factories of Lancashire, England, at present spin about 155,000,000 miles of thread in a day, so that in six seconds

they make enough to go around the Earth. In one minute they spin enough to reach from here to the Moon. The product of 18 days would reach from the Sun to Neptune. Counting 310 working days in a year, it would take them, at this rate, 500 years to spin enough thread to reach to the nearest star.

If one end of this thread were to be made fast to some place on our equator, the daily rotation of the Earth would wind up 25,000 miles of it every day. At this rate it would take about 300 years to wind up that part of the thread between us and Neptune. But to wind up the whole of the thread between us and the nearest star would take *2,500,000 years.*

Let us suppose that this thread is all wound around the Earth, and that the size of the thread is such that a rope of it an inch in diameter contains 10,000 threads. Then the entire skein would make a rope nearly 26 feet in diameter around the entire Earth.

Let us suppose that four miles of this thread weighs one pound. Then that part of it between the Sun and Neptune will weigh 340,000 American tons. And the same-sized thread reaching to the nearest star will weigh 3,000,000,000 American tons. If twenty tons of it were to be loaded on one railroad car, it would take 17,000 cars to carry that part between the Sun and Neptune, and the thread reaching to the nearest star would take 150,000,000 cars to hold it all.

A SPIDER'S THREAD

These numbers are still too large to be realised by the human mind as at present constituted. Fortunately, however, there is a way of considerably reducing them.

The thread spun by some spiders is so extremely fine and light that a single pound of it would be long enough to reach around our Earth. Let us see if we cannot get more reasonable weights by using this light and invisible thread.

To reach to our Moon would require nearly 10 pounds of it. To go to the Sun would take 3,712 pounds. Neptune's distance would require 56 American tons of it.

Fig. 44. — Eye-piece of the Great Lick Telescope

But to reach to the nearest star would take *500,000 tons.* At twenty tons to the car, this would take 25,000 cars to carry it all. At 35 feet to the car, these would make a train of cars 167 miles in length. This train would require 500 powerful locomotives to move it.

A QUARTZ FIBRE

We can get still better results by taking a quartz fibre like those used in a torsion-balance for weighing the Earth. They can be made one-hundred-thousandth of an inch in diameter, with tapering ends which thin off to the millionth of an inch. No microscope can show a fibre of this latter size, but its presence can be made apparent by means of photography. Nine and a half grains of this invisible quartz fibre (equal to one seventieth of a cubic inch) would reach to the Moon. Half a pound of it would go nearly to the Sun. Sixteen pounds would reach to Neptune. But it would take 72 American tons (equal to a cube of 9 feet 4 inches) to go to Alpha Centauri.

ONE CENT A MILE

If a railroad could be constructed to the nearest star, and the fare made one cent a mile, a single passage would cost *$250,000-000,000.* This would make a 94-foot cube of pure gold. The coined gold in the world amounts to $4,000,000,000, about equal to a 24-foot cube. It would therefore take more than 60 times the world's stock of coined gold to pay the fare of one passenger. *Let us save up our money and go when the line is built!*

A TIRELESS WHEEL

One more illustration will bring this chapter to a close.

Let us suppose a wheel to be turned at the speed of 100 revolutions in a second of time. This is equal to 6,000 times in a minute. At that speed it will go around 1,000,000 times in a little less than three hours. To go around as many times as there are miles between us and the Sun would take nearly eleven days. To go around as many times as there are miles between the Sun

and Neptune, the outside planet, would take nearly eleven months. But to go around as many times as there are miles between us and the nearest star outside our system would take nearly *8,000 years.*

These comparisons will do for the present. Let us take a rest — till the next chapter.

CHAPTER VII

SOME MORE DIMENSIONS

"That collection of stars which we call the Universe is limited in extent. . . . This does not preclude the possibility that far outside of *our* Universe there may be other collections of stars of which we know nothing."

— *Prof. Simon Newcomb.*

"Then the angel threw up his glorious hands to the Heaven of Heavens, saying: 'End is there none to the Universe of God. Lo, also, there is no beginning!'" — *De Quincey.*

A LONG SHEET OF PAPER

A VERY good way to get an idea of the relative distances of the heavenly bodies is to mark them off, on a small scale, on a long sheet of paper.

In order to do this properly, get a 1,000-pound roll of paper, like that on which magazines are printed.[1] Set up a bench or table, about 4 miles long, and unroll the paper on it. Draw a straight line down the middle of it, from one end to the other. We can now choose a unit of measure, and mark off the distances along this line.

Let us make a mark to represent the Sun, and another, one inch away, to represent the Earth. Then one inch will stand for 93,000,000 miles. On the same scale, Mars, the ruddy planet, will be 1½ inches off; Jupiter, the largest of the planets, will be 9½ inches distant; Uranus will be 19 inches off; and Neptune, the farthest of all the planets, will be 30 inches away.[2] The distance that light will travel in *one year* will be

[1] Such a roll is 20,250 feet long and 39 inches wide.

[2] The orbits of all the principal planets are on nearly the same plane. Therefore, on the above scale, the Solar System could be contained inside a round disc of wood five feet in diameter and two inches thick. Very few even of the small planets (asteroids) would ever go outside of this thin disc.

represented by one mile. The nearest star, on the same scale of one inch to the Sun's distance, will be more than four miles away. And Sirius will be eight and a half miles distant.

But stay! Our long sheet of paper is too short. Let us erase these marks and try a smaller scale.

In order to get the most convenient unit, measure off a 12-inch line and divide it into ten equal parts. Then divide one of these parts also into ten. This will give us the *one hundredth of a foot* for a unit. We may regard it as equal to *one eighth of an inch*, although it is really a trifle shorter.

If we make this little unit represent a mile, the distance of our Moon from us will be represented by 800 yards. It is quite evident that this scale is too large for our purpose. We must choose a smaller one.

As our Moon is nearer to us than any of the other heavenly bodies, we will let our little unit represent the Moon's distance.

First, make a mark, to represent the Sun, at one end of our long sheet of paper. Then put another mark, nearly four feet away, to stand for the Earth, with a quarter-inch circle around it to represent the Moon's orbit. Neptune's place may now be marked out, at a distance of 117 feet from our starting-point. The position of the nearest star will be about 200 miles farther on.

As our paper is again too short, we will reduce the scale, and regard our unit as representing the distance of the Earth from the Sun. Then Neptune's distance will be 3½ inches, and that of Alpha Centauri will be 900 yards.

Even this small scale is too large for some of the star-distances which have been approximately ascertained. So we will try again. This time we will represent the distance of Neptune from the Sun by our unit, so that the entire Solar System will be about the size of a pea. Every eighth of an inch will thus represent 2,790,000,000 miles:

At last we have succeeded in our efforts to get some of the stars on to our paper. The distance of Alpha Centauri will on this scale be only 90 feet. Sirius, the brightest star in the

heavens, will on the same scale be represented by a microscopic grain of sand, 180 feet away, yet glaring with such an overwhelming intensity of light as sometimes to throw shadows on the invisible point which represents the Earth.

The great majority of the visible stars, however, on the above scale of one eighth of an inch to the distance of Neptune, will be scores and hundreds of miles away. So that we shall have to try some other way of visibly representing their distances.

SOME BIG SQUARES

If, instead of using a straight line on which to represent distances, we use different-sized squares for the same purpose, we shall perhaps be more successful in appealing to the eye.

Take a square piece of white pasteboard which measures a foot each way. On each edge mark off ten equal divisions. Then with pencil and ruler join the opposite marks, thus making a kind of chess-board with 100 equal squares. In the same way divide up one of these squares into 100 equal squares. Each of these smaller squares will be nearly one eighth of an inch across.

Taking one of these tiny squares as a unit (1), the whole square will contain one hundred units (100), and the entire pasteboard will be equal to ten thousand units (10,000).

Now if each of these little squares or units be made to represent one mile, it will take a square nearly five feet across to represent the distance of the Moon from the Earth. To represent the Sun's distance from us, it will take a chess-board measuring 96 feet each way. Neptune's distance will be represented by a square measuring 525 feet. The distance of the nearest star will take a chess-board measuring 9½ miles each way, and covering 90 square miles of land. It must be remembered that, on this scale, every eighth-of-an-inch square of surface represents a mile between us and the nearest star.

It is evident that we shall have to try a smaller scale if we are to make the stellar distances visible to the eye by means of squares. If we let one of the tiny squares represent the distance

between us and the Sun, then the distance of the nearest star will be represented by a chess-board more than five feet in diameter.

If we reduce the scale still more, and make our unit represent the distance of Neptune from the Sun, then the distance of Alpha Centauri will be represented by nine tenths of our 12-inch chess-board.

SOME SOLID COMPARISONS

In order to bring our measures still more within the reach of the eye, the little unit just used may be cubed. It will then be a solid block, measuring nearly one eighth of an inch every way.

Regarding this cube as the equivalent of a mile, the Moon's distance will be represented by a 7½-inch cube. The Sun's distance will take a cube 4 feet 6 inches every way, and Neptune's will take a 14-foot cube. The distance of Alpha Centauri will be represented by a cube measuring 290 feet every way.

A GREAT VOID

Let us now consider in other ways the vastness of this apparently empty space between our system and the nearest star.

Make a circle, two inches across, on the ground. Let this circle represent our entire Solar System, with the Sun in the centre. Then a similar circle including the nearest star will, on the same scale, be 1,524 feet across. That is to say, it will make a circular race-track nearly a mile around.

If these circles be regarded as solid spheres or globes, then the larger one, representing the *intense loneliness* of our Solar System, will be equal to 766,000,000,000 globes like the smaller one that represents the size of our system.

LONG-RANGE CANNON

It is difficult for one who is not an astronomer to realise the enormous light-grasping power of our great telescopes. Most of us, indeed, fail to realise even the power of the unaided eye to penetrate space. Here are a few illustrations of both.

FIG. 45. — YERKES OBSERVATORY, WILLIAMS BAY, WISCONSIN

FIG. 46. — THE FORTY-INCH REFRACTOR OF THE YERKES OBSERVATORY: THE LARGEST IN THE WORLD

Suppose that our Sun were to leave us and go off in the direction of Sirius at such a rate as to double its distance in one year. And suppose it were to continue receding at the same rate for an indefinite period. In 100,000 years it would be about as bright as Sirius, though the latter would still be 5½ times as far away from us. In 550,000 years it would pass Sirius and appear to us about as bright as the Pole Star. In 3,000,000 years it would be just visible to the naked eye, and its light would take 46 years to reach us. After receding for 750,000,000 years, it would still be visible to a telescope with a 50-inch object-glass or mirror, and its light would take more than 11,000 years to reach us.

Suppose that Sirius were to recede from us at the rate of 1,500,000 miles per second (eight times the speed of light), so as to double its distance in one year. In 30 years it would be just visible to the naked eye, and its light would take 240 years to reach us. After receding for 7,500 years it would still be visible with a 50-inch telescope, and its light would take about 60,000 years to reach us.[1]

Suppose that a star that is just visible to the naked eye were to recede from us at such an inconceivable rate as to double its distance in a year. It would be about 250 years before it would be lost sight of by the same 50-inch telescope.[2]

Let one inch represent the distance of the farthest star visible to the naked eye. Then the distance at which our largest telescopes would lose sight of it will be represented by about 21 feet.

This last illustration may be put in another form. If a globe two inches in diameter be supposed to contain all the stars visible to the naked eye, then it will take a globe 42 feet thick to contain all the stars visible to our great telescopes.

[1] It would be more correct to say that stationary stars equal to Sirius would be just visible at those distances, and that their light would take so long to reach us.

[2] The same remark applies here.

ETERNAL LIGHT

Suppose that (with the exception of our Sun) every star in the Universe were to be blotted out of existence to-day, we should not know of it for several years. We should continue to receive the light which is already on the way, and the stars would still appear to twinkle as they have always done. In a little over four years the nearest star would suddenly go out of sight. But no one would miss it except the astronomer. After another four years the mysterious disappearance of Sirius would attract more general attention. In a century a few more would be missed, but the majority would remain visible for thousands of years. Some of the stars seen in the most powerful telescopes may be so far off that the light we now see left them when Great Britain was part of the mainland of Europe, and the Britons were fighting the hippopotamus, the hyena, and the sabre-toothed tiger.

REASON *VERSUS* IMAGINATION

I have now given sufficient illustrations of the unthinkable vastness of the visible Universe. It is no use trying to realise even ascertained facts of such immensity. As Dr. J. W. Draper says, "distances and periods such as these are beyond our grasp. They prove to us how far human reason excels imagination, the one measuring and comparing things of which the other can form no conception, but in the attempt is utterly bewildered and lost."

NUMBERING THE STARS

"Look now toward heaven,
And count the stars.
Tell the number of them
If thou art able." — *Genesis* xv, 5 (A. Zazel).

The next question is, How many stars are there in the visible and invisible parts of our Universe?

This, like many other celestial problems, can be only partially answered. The unaided eye can perceive about 3,000 in each

hemisphere. Argelander's great catalogue contains a list of over 300,000, all visible with a pocket telescope. A good three-inch achromatic telescope brings about 1,000,000 in sight. But they are shown by the giant instruments of our great observatories in such multitudes that they cannot be counted. We have to be satisfied with more or less approximate estimates of their numbers.

Yet every improvement in light-grasping power brings millions of fresh ones into sight, and shows the "backspace" of sky all glowing with the light of invisible suns too far off to be separately distinguished.

It has of late years been found possible to attach a photographic apparatus to a telescope, so as to make the luminous bodies in the heavens take their own pictures. Whole groups of stars are photographed on one plate. Complete sets of these star-photographs (embracing every nook and corner of the celestial sphere) are taken every year, and carefully compared with one another, to find out what changes are going on in the heavens. It will not be long before every star photographically visible to the most powerful telescope will have its present position accurately defined on these photographic charts.

By a prolonged exposure of the sensitive plate even invisible stars gradually photograph themselves, so that immense numbers of stars have been discovered which no eye can see, even with the aid of the same telescope. "Many ten thousands" of stars have often registered themselves on a single plate. In one case over 400,000 were actually counted.

It has been estimated that for every star visible to the naked eye there are at least 50,000 visible to the telescopic camera. This would bring the number of visible stars to about 300,000,000.

Yet even the picture-taking power of the photographic telescope has its limits. In photographing the Milky Way its plates (when long exposed) are sometimes clouded by constellations too faint, through distance, for the individual stars to record themselves. However much the telescope and its adjuncts may be improved in the future, they will always fail to penetrate

more than a certain distance into space. Beyond that limit there may still be, as George Sterling suggests, the —

— "fires of unrecorded suns
That light a heaven not our own."

IS THE UNIVERSE LIMITED IN EXTENT?

"The centre of space is everywhere, and its circumference nowhere." — *Blaise Pascal.*

We know, by abstract reasoning, that space is limitless. The question arises, Is there a limit to the distribution of luminous and non-luminous bodies in that limitless space? In other words, Is there a limit to the Universe?

Professor Newcomb deals with the question as follows. Suppose a globe to encircle and include all the stars visible to the naked eye. And suppose another of double radius, a third of treble radius, etc., with similar distribution of stars. As the light received from a given luminous area or surface is in the inverse ratio to the square of the distance, each shell will send us an equal amount of light. If there is no limit, then, unless some cause produces a loss of light, the whole sky will be as bright as the Sun. As this is very far from being the case, it is evident that there is either a limit or a loss of light.

It is not impossible that light itself may have limits to its continuous flight: that it may be intercepted by dark bodies on its way to us, or that its waves may lengthen out till all vibration ceases. Dr. J. J. See says on this subject:

"In the exploration of the sidereal heavens it is found that the more power the telescope, the more stars are disclosed; and hence the practical indications are that in most directions the sidereal system extends on indefinitely. But the possible uniform extinction of light due to the imperfect elasticity of the luminiferous ether, and the undoubted absorption of light by dark bodies widely diffused in space, seem to preclude for ever a definite answer to the question of the bounds of creation."

FIG. 47. — MILKY WAY SURROUNDING MESSIER II.

Photographed with a portrait-lens, by Barnard, at Yerkes Observatory.

Fig. 48. — The Star-cluster Messier II.

Photographed with the great Yerkes refractor, by Ritchey.

So George N. Lowe may be right when he says:

> "Beyond the thirty thousand years
> Of light, the giant systems swing —
> Vast, unknown suns and flaming spheres —
> And great worlds from their girdles fling."

INCOMPREHENSIBLE, YET TRUE

I once put the following question to the late Richard A. Proctor:

"Let us suppose that a man could reach, in one second of time, the remotest star visible. Let us also suppose that he could continue on at the same speed, in a straight line, to all eternity. Would he ever get to the end of suns and worlds, or would he always have as many in front of him as he had behind him? The latter proposition seems absurd, yet appears to be a necessary consequence of the theory that 'end there is none, nor is there yet beginning.' But if, on the other hand, the last star could be reached in every direction, then the Universe not only has bounds, but is as a mere grain of sand in the infinite desert of space. Of course I use the word Universe in its largest sense."

Mr. Proctor's reply was as follows:

"I fear that to this question there is but one answer, 'We don't know.' *The infinite, which necessarily is, is necessarily incomprehensible.*" [1]

QUANTITY OF MATTER IN UNIVERSE

Of late years an attempt has been made to ascertain the total amount of matter in the Universe by estimating the gravitational force acting on individual stars. One of these, known as 1,830 Groombridge, is moving at a speed of 200 miles per second. Let us suppose that it has "fallen" from a practically infinite distance, pulled by the combined attraction of everything in our Universe. It has been estimated that more than 30,000,000,000 suns like ours would be necessary to produce

[1] See "Knowledge," June 1, 1886, page 254.

the observed speed. If our Sun be taken as an average star, this would indicate that, for every star visible to the telescope, there are more than a hundred that are invisible, either from distance or because they have ceased to be luminous.

If this method be trustworthy, it will give us some idea as to the dimensions of *our* Universe. But it does not disprove the existence of other and similar universes at practically infinite distances from ours, and from one another. For if it did, then the observed motion of a comet visiting our Solar System (being the result of the total attraction of the matter in the system), could be used as a proof of the non-existence of anything outside of the Solar System. And this would hardly be doing justice to the myriads of Stellar Systems which are known to surround our own.

The Law of Gravitation, which has just been alluded to, will be dealt with in Chapter XV.

OUTSIDE UNIVERSES

The study of the visible Universe shows that it is composed of ascending series of similar systems. For example: (1) *atoms* appear to be spheroidal "star-clusters" of still smaller particles in motion; (2) *suns* and *worlds* are rotating spheroids built up of these atoms; (3) *stellar systems* are rotating spheroids built up of suns and worlds; (4) the visible *Universe* appears to be a rotating spheroid built up of a Milky Way of stellar systems.

It is possible that this largest spheroid, which we call the Universe, may be only one out of innumerable similar spheroids, rotating at practically infinite distances from each other, and forming a still vaster rotating spheroid.

These speculations could be extended *ad infinitum* at both ends of the series. It would, however, be a waste of time to consider them seriously, they only serve to show how little we really know of the great "Riddle of the Universe."

CHAPTER VIII

THE PRINCIPLES AND APPLICATIONS OF THE SPECTROSCOPE

"And Elohim spake unto Noah and to his sons with him, saying . . . I will establish my covenant with you; neither shall all flesh be cut off any more by the waters of a flood; neither shall there any more be a flood to destroy the earth. And Elohim said: This is the token of the covenant. . . . I do set my bow in the cloud, and it shall be for a token of a covenant between me and the earth, . . . and I will look upon it, that I may remember the everlasting covenant." — *Genesis* ix, 8–16.

THE BRIDGE OF BIFROST

THE rainbow has always been a source of wonder and admiration to mankind. Before history began, men were blindly theorising as to the cause and meaning of the wonderful arch of colours which, phantom-like, seemed to span the earth and reach to heaven. Among the old Norsemen it was known as the Bridge of Bifrost, and was supposed to connect the abode of the gods with that of their subjects on earth. No mortal could set his foot on this bridge, but the gods used it when they had business to transact or mischief to work in the lower regions.

In more recent times its nature and cause have been ascertained, and its glorious colours have been reproduced by allowing the Sun to shine through a three-cornered glass prism. Marvellous to relate, the fragments of rainbow thus produced have not only helped chemists to solve some of the mysteries concerning matter on earth, but have also enabled astronomers to wrest from high heaven many of the secrets relating to the chemistry, constitution, and movements of the heavenly bodies, some of which still bear the names of the old deities.

If the old Norse religion had only survived until now, how easily might the priests of Odin have proved the inspiration of the old records! They could now show that the apparently childish stories (though not literally true) have a hidden symbolical meaning and refer to facts that only Gods could have then been acquainted with.

But, alas! the new light has come too late. The old narratives have been replaced by others. The Bridge of Bifrost is now the only remaining proof that the life of the world was once practically destroyed by an all-wise Creator, in a justifiable exasperation at the moral imperfections with which he had knowingly endowed its most perfect inhabitants.

THE KEYS TO THE UNIVERSE

The rainbow and its artificial imitations are caused by the refraction of light, a property without which mankind would have been for ever left in the dark as to the outer Universe. The study of the peculiarities of this refraction has given us the telescope and the spectroscope — two master keys which are unlocking the mysteries of the Universe to man. The two discoveries have indeed been described by enthusiastic scientists as the most important events that have taken place on earth since history began. The telescope, the camera, the spectroscope, and even the human eye itself, would have been impossible without the refraction of light upon which they — and the rainbow — depend.

The instrument into which the rainbow-like *spectrum* has been harnessed is known as the *spectroscope.* A few words concerning the principles utilised in this instrument will help us to grasp some of the facts which have been brought down from heaven by its means.

MATTER AND ETHER

There appear to be in Nature two forms of *substance* entirely distinct from each other in structure and functions. Every

nook and corner of infinite space appears to be packed with one or the other of these two forms of substance.

I. *Matter.* — That with which we are most familiar is commonly known as *matter.* It is made up of *atoms,* possesses *weight,* and exists as a *solid, liquid,* or *gas,* according to surrounding conditions.

II. *Ether.* — The other goes by the name of luminiferous (or light-bearing) *ether.* This ether is not made up of atoms, but appears to consist of homogeneous particles or *corpuscles.* These are estimated to be about a thousand times less (in mass) than the smallest atoms of ordinary matter. On account of their being the carriers of so-called negative electricity they are sometimes called *negative particles.*

This ether is practically *without weight,* being millions of millions of times thinner than air. It probably fills to saturation all space which is not occupied by ordinary matter; even filling the little spaces between the atoms of matter. Some of the phenomena produced by it are explainable only on the theory that it can pass through suns and worlds as water passes through a sieve, or as light passes through a massive sheet of glass.[1]

VIBRATIONS OF ETHER

All matter has a life of its own and is in continuous motion. The various motions of matter produce corresponding vibrations in the ether, which carries them to inconceivable distances. Some of these vibrations become sensible to us in the form of *light;* others are recognisable as heat, electricity, magnetism, etc.

REFRACTION OF LIGHT

Light may be regarded as produced by wave-like undulations of the elusive ether which appears to fill all space. The un-

[1] This may at first seem incredible, even with our recent experience of Roentgen rays. But it must be remembered that it is not a whit more wonderful than the commonplace yet astounding fact that light can pass, almost without let or hindrance, through solid glass or ice.

dulations of light radiate through this ether like the ripples which spread over water when a pebble is thrown into it. Or they may more correctly be likened unto the vibrations of air which start out in all directions from a centre of vibration and ultimately become sensible to the ear as *sound*. Like the waves of sound, the ethereal undulations of light vary in length. That is to say, the interval between the summit of one wave and that of the next varies in length in different kinds of light. When

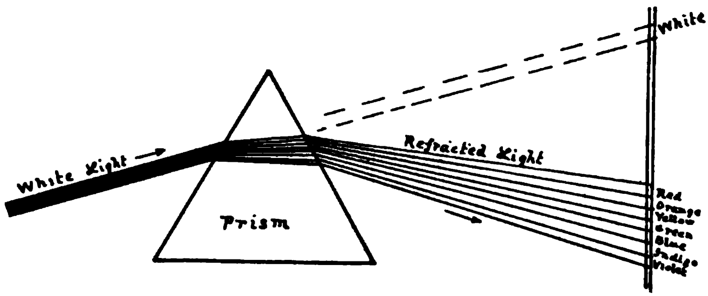


FIG. 49.—A PRISM AND ITS SPECTRUM

a ray of white light passes through a glass prism, the greater density of the medium causes it to be bent or *refracted*. The light, instead of coming out opposite to where it entered the prism, comes out at an angle, the bend being toward the side where the prism is thickest. The inequality of wave-lengths causes this refraction to be unequal also, and the white light splits up into an infinite number of shades, the best known of which go by the names of violet, indigo, blue, green, yellow, orange, and red (see Figure 49).

Of these colours the violet rays have the shortest wave-length and are bent the most from their previous course. The red waves are the longest, and are bent the least.

This visible spectrum is only a part of a much longer spectrum, the rest of which is invisible to the eye, though recognisable by other means. The short waves at the violet end are characterised by the intensity of their actinic or chemical properties,

while the long ones at the red end give out more heat. The violet waves are so short that 61,000 of them reach only an inch, while the red ones are so long that there are only 33,000 of them to an inch. They all travel at the same speed, 186,000 miles in a second of time.[1]

THE SPECTROSCOPE

For convenience the glass prism is placed at the elbow of an instrument that looks like a bent telescope and is commonly

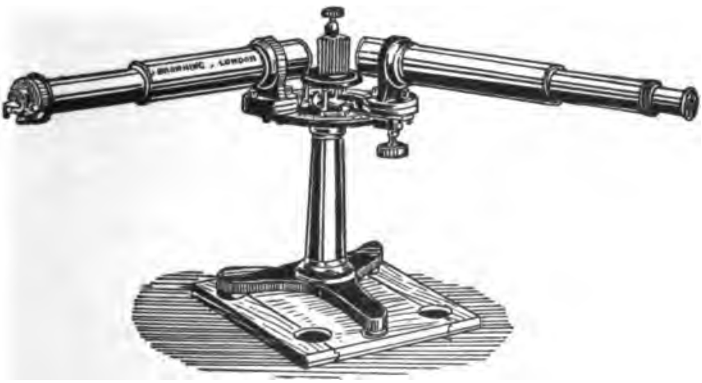


FIG. 50. — A ONE-PRISM SPECTROSCOPE

known as a spectroscope (see Figures 50, 51, and 52). A ray of white light entering at one end through a narrow slit passes along the tube until it comes to the prism. There it is bent and split up into the colours of the rainbow. This row of colours is known as a *spectrum*, and is examined directly from the other end of the "bent telescope."

The spectroscopes now used are more complicated than the above, with a "battery" of prisms (or with a corrugated mirror

[1] It is interesting to note that if the prism, instead of being straight, is bent around a centre into a lens-form, it brings the light to a focus, and forms the basis of the telescope and microscope. In these instruments special means are taken to *avoid* the separation of the various colours, but in the spectroscope special means are taken to *increase* the dispersion.

called a diffraction grating), but they all depend on the same principle, so need not be here described.

VARIETIES OF SPECTRA

Now it is found that different sources of light do not give the same spectrum when examined through the spectroscope. There are, in fact, several distinct classes of spectra, which are here given.

I. *Continuous Spectrum.* — Light from an incandescent substance in a solid or liquid state, or from a glowing gas which is *under great pressure,* gives a *continuous spectrum,* all the colours

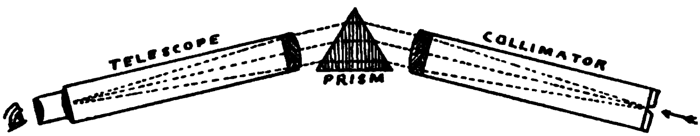


FIG. 51. — SECTION OF A ONE-PRISM SPECTROSCOPE

being fully and evenly represented. In this case it is evident that light of every wave-length is being given off (see Figure 53, *a*).

II. *Emission or Radiation Spectrum.* — Light from an incandescent gas which is *uncompressed,* and therefore *free to vibrate* at its own rate, does not give a continuous spectrum, as in the first instance. It merely gives a limited number of *bright lines,* crossing the long streak where the spectrum should have been. These bright lines vary in colour according to their position in the (absent) spectrum. This shows that a glowing gas, when unconfined, only gives out light of certain definite wave-lengths (see Figure 53, *b*, *d*, *e*).

III. *Absorption Spectrum.* — When light of the first class *passes through a mass of uncompressed gas,* its otherwise continuous spectrum becomes to a certain extent discontinuous. It is crossed by certain *dark lines,* making the spectrum look as though there were a ladder in front of it, with numerous black rungs at irregular distances from one another. This shows that light of certain wave-lengths is absent, being *absorbed* by the

uncompressed gas through which the light passes (see Figure 53, *i*, etc.).

IV. When the source of light is *partly solid or compressed matter*, and *partly uncompressed gas*, the result is a spectrum crossed by *both bright and dark lines or bands* (see Figure 53, *h*).

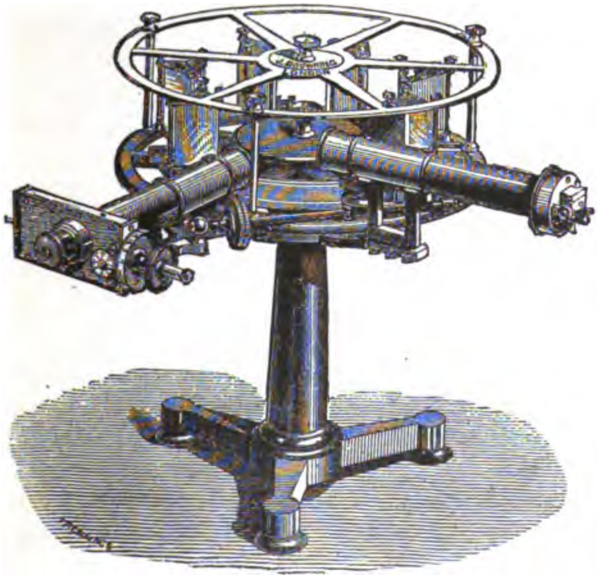


FIG. 52. — A COMPOUND SPECTROSCOPE

SPECTRUM ANALYSIS

Chemists have discovered that there are only about eighty different kinds of matter on the accessible parts of our globe, and that only about a quarter of these are abundant or important. All the tens of thousands of different substances on earth (whether solid, liquid, or gaseous) consist of these *elements*, either separate or in partnership with one another.

Now the great importance of the spectroscope depends on the fact that *every one of the elements*, when in the condition

of glowing gas, produces *its own special lines* in the spectroscope. By examining the spectrum of an unknown substance, the elements of which it is composed can be ascertained. This way of examining substances is therefore known as *spectrum analysis.*

It has also been found that when light passes through a certain uncompressed gas, that gas *absorbs the same rays of light which it naturally emits* when it is itself an uncompressed source of light (see Figure 53, *b*, *c*).

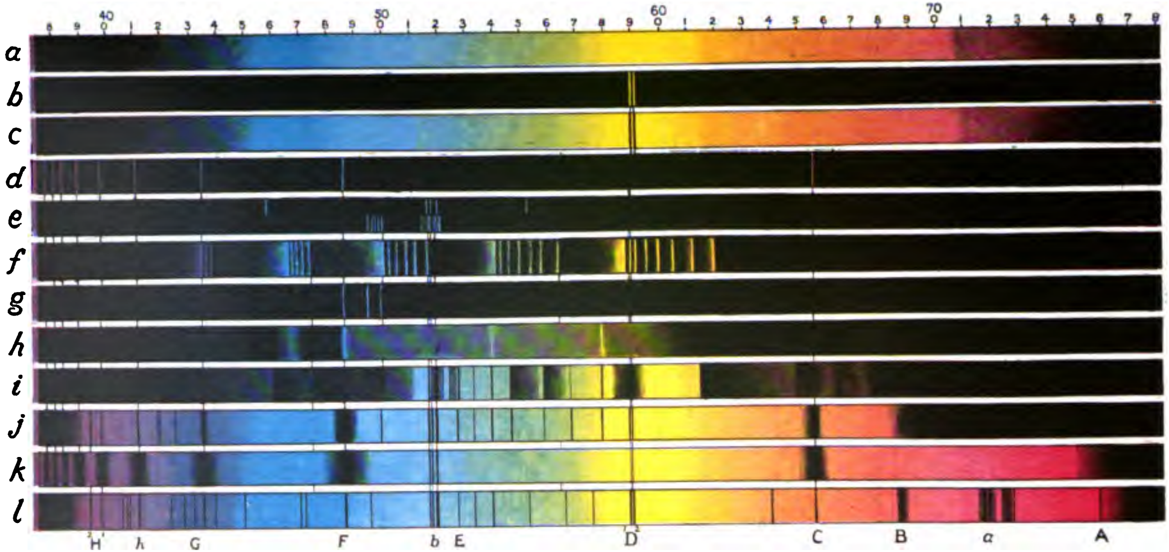
Bearing these facts in mind, let us turn back to reconsider the four classes of spectra given above.

When the spectrum is of the *first class* (*continuous*), we do not get much information with regard to the source of light. We know that the light does not proceed from an uncompressed gas, but we cannot tell whether it is given off by a solid, a liquid, or by a compressed gas.

When it is of the *second class* (*emission*), consisting entirely of a limited number of *bright lines*, we know that the light proceeds from a glowing gas that is not under great pressure. And we can tell what particular elements that gas consists of or contains. Certain lines prove that it contains *hydrogen;* other lines tell of the presence of *sodium.* Another set is caused by iron vapour; and so on, with all the elements (see Figure 53, *b*, *d*, *e*, *f*).

When the spectrum is of the *third class* (*absorption*), it is nearly continuous, but is crossed by *dark lines.* In this case we know that the luminous body, whatever it is, is surrounded by uncompressed gas which has absorbed certain light-waves and so prevented them from reaching us, and, as in the second class, we can tell what particular elements that gas consists of or contains; for the element which produced a certain set of *bright* lines when it was a source of light produces the same set of *dark* lines when it surrounds the source of light or comes between the source of light and its spectrum. Hydrogen, sodium, iron, etc., are in the one case recognised by their peculiar bright lines, and in the other case by identical sets of

Fig. 53. — Laboratory and Celestial Spectra. After Lockyer



(*a*) Continuous Spectrum
(*b*) Spectrum of Sodium (radiation)
(*c*) Spectrum of Sodium (absorption)
(*d*) Hydrogen
(*e*) Magnesium } high temp. / low temp.
(*f*) Carbon
(*g*) Nebula
(*h*) Lalande 13412
(*i*) Alpha Orionis (Betelgeuse)
(*j*) Alpha Cygni (Arided)
(*k*) Alpha Lyræ (Vega)
(*l*) Our Sun

dark lines. The difference is one of condition, not of substance (see Figure 53, *b*, *c*).

A spectrum of the *fourth class*, crossed by both bright and dark lines or bands, denotes that the source of light is either a mixture of solid and gas, or of compressed and uncompressed gases. The different sets of lines denote the presence and condition of their respective elements, as in the other classes.

In spite of the one element of uncertainty mentioned, the above results are remarkable achievements, even when applied to substances actually present in the chemist's laboratory. They have led to the discovery of hitherto unknown elements and to a great advance in chemistry generally. But still more remarkable is the fact that this *spectrum analysis* can be applied to a distant source of light. Large numbers of the terrestrial elements have been recognised in the sierra or atmosphere of our Sun, and even the stars are not too far off to be cross-examined by the spectroscope as to their chemical composition and physical condition.

The spectrum of a star being very faint, it is observed by a spectroscope attached to a telescope, the combination being known as a tele-spectroscope (see Figure 54). Sometimes the spectrum is photographed for future examination and comparison. The instrument which accomplishes this is termed a spectrograph (see Figure 55).

SPECTRA OF STARS

Our Sun and the brighter stars, when examined with the spectroscope, give spectra of the *third class* (*absorption*). That is to say, their spectra are fairly continuous, but are crossed by dark lines. This shows that such stars are all related to one another, so that the study of any one of them will throw light on all the rest. They are all suns, somewhat similar to, but not identical with, our Sun (see Figure 53, *i*, *j*, *k*, *l*, *m*).

The fainter stars have not yet been satisfactorily examined with the tele-spectroscope, on account of the small quantity of light we receive from them. Still, a certain amount of infor-

mation has been obtained concerning their composition and condition.

SPECTRA OF NEBULÆ

When the heavens are examined with the help of a telescope of some considerable power, enormous numbers of stars are revealed. But, besides these stars, the telescope also brings into sight large numbers of tiny patches of hazy light. These look as though they might be clusters of stars which are too far off to be separately distinguished. From their cloud-like appearance these streaks and patches are termed *nebulæ*.[1]

With two or three exceptions these nebulæ are not visible to the naked eye, and the vast majority of them require very powerful instruments to bring them into view.

Modern telescopes have in many cases proved that they are really composed of stars, and every increase in telescopic power has resolved fresh nebulæ into star-clusters. At one time it was thought that all would eventually be proved to be nothing more or less than clusters of faint stars. It has been ascertained, however, that there are two main classes of so-called nebulæ, and that only those of one class are composed of stars.

PSEUDO-NEBULÆ (*Star-Clusters*). — All of those nebulæ which have been shown by the telescope to be really star-clusters give absorption spectra similar to those of the visible stars (Class III), and some nebulæ which have not yet been resolved into stars by the telescope have been found to give similar spectra. As a rule the spectrum of a star-cluster is so faint that it consists of a mere streak of light in which the colours and lines are imperceptible.

TRUE OR GASEOUS NEBULÆ. — Other nebulæ, however, show by their bright-line spectra (Class II) that they are not composed of suns, but are immense masses of glowing gas, ***not under pressure.*** Those which are comparatively bright give a number of bright lines, five of which are much more prominent than the

[1] The Latin word *nebula* means a cloud, fog, mist, or smoke. It may be regarded as a diminutive of *nubes*, a cloud.

FIG. 54. — TELE-SPECTROSCOPE

Attached to a telescope for the purpose of viewing celestial spectra. Lowe Observatory.

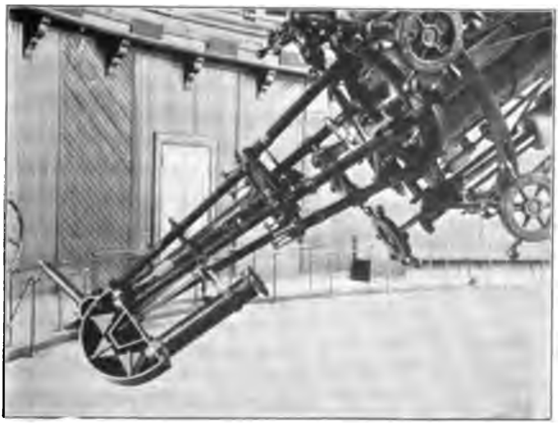


FIG. 55. — THE MILLS SPECTROGRAPH AT LICK OBSERVATORY

For photographing spectra of celestial objects.

rest. In the fainter nebulæ only one of the lines is visible, owing to the small quantity of light which reaches us; but it is readily distinguished from the practically continuous spectrum given by star-clusters, etc.

CLASSES OF STARS, ETC.

Stars and other self-luminous heavenly bodies have been divided into a number of classes, according to their colours and spectra; but no hard-and-fast line can be drawn between them, as there are many which give intermediate spectra. The following are perhaps the best defined classes, starting with the youngest.

A. BLUE-GREEN NEBULÆ (*Gaseous Nebulæ*). — Nearly a hundred of the nebulæ have a bluish-green tint which distinguishes them from all others. They give an emission spectrum, consisting entirely of a few ***bright*** lines (Class II) on a ***dark background***. This indicates that they are entirely composed of uncondensed gases, so extremely diffuse as to be transparent in spite of their thickness, which is sometimes many millions of miles. The lines are those belonging to hydrogen, helium, and "nebulum" (see Figure 53, *g*). The lines are thin, denoting a comparatively ***low temperature*** and the absence of pressure. One of these lines, in the blue-green part of the spectrum, is so bright that it gives the blue-green tinge peculiar to nebulæ of this class when seen through the telescope. It is due to an unknown substance which has been named "nebulum."

About half of these gaseous objects are termed ***planetary nebulæ***, from the symmetrical planet-like disc which they exhibit when seen through a powerful telescope (see Figure 99).[1] The rest are generally irregular and shapeless, like the Great Nebula in Orion (see Figure 68), and the Trifid Nebula in Sagittarius (see Figure 67). The so-called Ring Nebula in Lyra is also gaseous. Recent photographs taken at the Ann Arbor Observatory by Professor Schaeberli show that its resemblance

[1] Some of the planetary nebulæ have a star-like nucleus in the centre.

to a ring is only apparent, and that it is really a spiral nebula (see Figure 66).

B. PEARLY-WHITE NEBULÆ. — Some thousands of nebulæ have a pearly-white appearance when seen through the telescope. They give a continuous spectrum, which denotes that they are either composed of matter in a solid state, or of gases under high pressure or great heat. Very little is at present known as to the actual condition of the matter composing these nebulæ. But in many cases it appears to be collecting in "centres of condensation," as though stars were in process of formation out of nebulous matter.

The Great Nebula in Andromeda (see Figure 64) belongs to this class, as do the *spiral nebulæ* generally (see Figure 63). The late Dr. Keeler estimated that there are at least 120,000 nebulæ within range of the telescopic camera, and that more than half of these show signs of a spiral structure.

C. NEBULOUS STARS (*Orion Stars*). — These consist of a faint nebulous haze with a star in the centre. They give broader hydrogen and helium lines than Class *A*, showing that the gases are hotter and more condensed. These stars are still in process of formation, and have not yet drawn in all of the nebulous matter around them. They are therefore *buried in the depths of a luminous haze* consisting chiefly of hydrogen and helium. *Examples*, the stars in the Pleiades and those connected with the Great Nebula in Orion.

D. BLUISH-WHITE STARS (*Sirian Stars*). — About 75 per cent of the brighter stars appear to belong to this class. Their spectra show all seven colours (Class III), but *the violet end is the most brilliant.* There are four broad dark lines belonging to hydrogen, *greatly condensed* and *very hot.* The metal lines are few and faint. One of the magnesium lines indicates a temperature about equal to that of the electric spark, — say about 20,000° F. The probability is that these stars are still surrounded by a *very deep, dense, and hot atmosphere* (chromosphere) of hydrogen, and that the high temperature prevents the formation in it of a bright cloud-photosphere of calcium, etc.

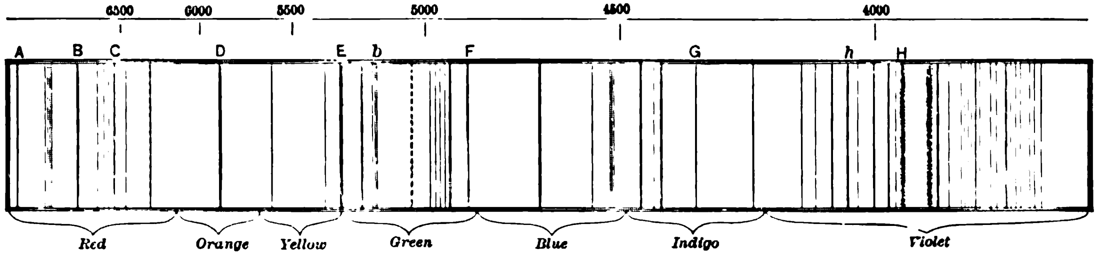


FIG. 56. — CHIEF LINES IN THE SOLAR SPECTRUM (HERSCHEL)

The above are the most conspicuous out of many thousands visible with the best spectroscopes. (*From Comstock's "Text-book of Astronomy," published by Messrs. D. Appleton & Co.*)

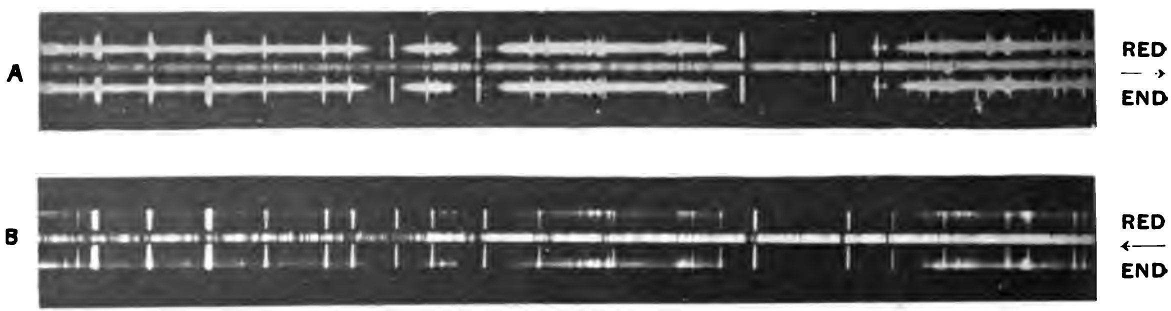


FIG. 58. — STAR SPECTRA SHOWING DISPLACEMENT OF LINES DUE TO STAR'S MOTION IN LINE OF SIGHT

(*a*) Lambda Aurigæ. Velocity + 66 kilometers per second (receding, 41 miles per second).
(*b*) Eta Cephei. Velocity — 86 kilometers per second (approaching, 53 miles per second).

Examples, Sirius, Vega, Altair, Rigel, and Arided (see Figure 53, *j*, *k*).

E. Yellowish Stars (*Solar Stars*).—This class includes about 23 per cent of the brighter stars. Their spectra show all seven colours (Class III), *the middle being the most brilliant*. The hydrogen lines are faint, denoting a *shallower atmosphere* or chromosphere. There are large numbers of very strong dark absorption lines, due to the presence of different metals (in the gaseous state) in the stellar atmospheres. Many of these metallic elements have been recognised by their special lines. One of the magnesium lines indicates a temperature not very far from that of the electric arc (6,300° F.), or at least it indicates a temperature lower than that of the electric spark. Probably 12,000° F. is not very far from the mark. The comparatively low temperature of the chromosphere—due to its shallowness—causes the formation of a layer of bright clouds known as the photosphere. This is composed of incandescent solid (or liquid) particles of calcium, etc.

If all the light from this brilliant photosphere reached us, the Sun and solar stars would all be of a pure white, and their spectra would be continuous (Class I), containing rays of all wave-lengths. But as they are surrounded by a chromosphere (or atmosphere) of metallic gases at a rather lower temperature, some of the light is absorbed. The absorption is greatest among the short waves, so that these stars all have a yellowish tinge. Their spectra are therefore of Class III, with many dark absorption lines due to the metallic gases in their chromospheres. *Examples*, Capella, our Sun, Procyon, Pollux, and Arcturus (see Figure 53, *l*; also Figure 56).

F. Orange-Red Stars.—This class includes about one per cent of the brighter stars. More than 60 of them are *irregular variables* of the Mira Ceti class. The spectra show all the seven colours (Class III), with the *red end most brilliant*. There are no hydrogen lines except when the stars are at their maximum of brilliancy. The metal lines are complex, and there are dark absorption-bands, with a *sharp, well-defined edge toward the*

violet. These indicate a dense and complex atmosphere of relatively low temperature, with chemical compounds. *Examples,* Aldebaran, Betelgeuse, Antares, and Mira Ceti (see Figure 53, *i*).

G. BLOOD-RED STARS. — The spectra are similar to those of Class F, but are more or less cut up by dark absorption-bands. These have a *sharp, well-defined edge toward the red end* of the spectrum, and are due to hydrocarbon vapours in the stellar atmospheres. In some stars these bands are so broad and dark that but little of the spectrum can be seen. Their light is in fact dying out. *Examples,* Mu Ceph, and 152 Schjellerup (see Figure 53, *m*; also Figure 57).

H. DARK SUNS. — These give out little or no light and heat, and therefore have no visible spectra. They are dead or dying suns. We know of their existence only when they have visible companions moving around the same centre of gravity. *Example,* one of the companions of the Pole Star.

RADIAL MOTIONS

Of late years the tele-spectroscope has given aid to astronomy in another and unexpected direction. Astronomers have long been able to watch and measure the movements (both real and apparent) of the heavenly bodies when those movements were more or less at right angles to the line of sight. But until recently they were unable to detect motions toward or away from us, except indirectly, by the increase or decrease of brilliancy and size.

A few years ago, however, it was discovered that, when a source of light is *approaching,* the lines which cross its spectrum are displaced toward the violet end, and that when it is *receding* they are displaced toward the red end of the spectrum.

This is due to the same cause that makes a locomotive whistle appear to fall in pitch the moment it passes the listener. While the engine was approaching the listener, the waves of sound reached his ear at shorter intervals than they would otherwise

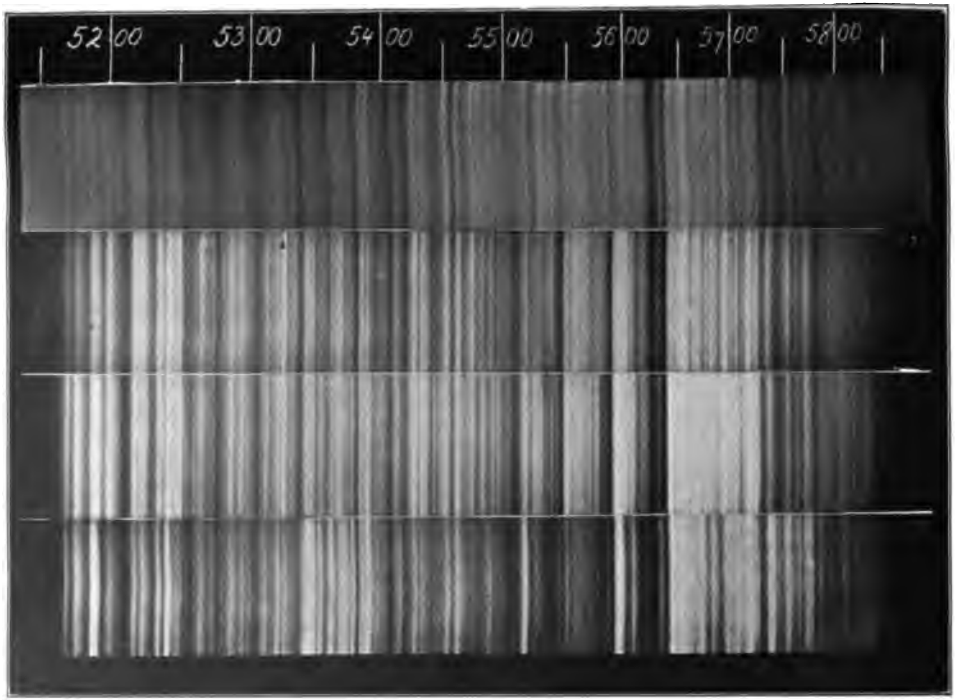


Fig. 57. — Part of the Spectra of Four Red Stars (Hale and Ellerman)

Showing how the dark band due to carbon increases in intensity as the star cools.

have done, and after it has passed him the reverse is the case. Hence the apparent change of pitch.

In the case of light (spectroscopically observed), the effect is a slight change of *position* instead of *pitch*. The waves are in fact crowded together and made shorter from crest to crest. This could not be measured or even recognised in a continuous spectrum, but in a banded one it is done with comparative ease by so arranging as to have a normal spectrum on each side of it for comparison (see Figure 58). The result is that we can not only tell that a certain object is approaching or receding from us, but can also tell how many miles it is moving in those directions per second.

This method of detecting and measuring radial motions (real or apparent) can be applied not only to those heavenly bodies whose distances are known, but also to those which are utterly beyond the reach of our space-measuring instruments. The only limit is that caused by deficiency of light.

It is possible that this principle may in time be found available for measuring star-distances which are too great for our present methods. It is proposed to measure the orbits of double stars spectroscopically, and then use the major axes as base lines.

At present, stellar distances can be roughly estimated up to 60 light-years, which is 15 times the distance of Alpha Centauri. Dr. See thinks that some day star-distances of 1,000 light-years may be determined by this plan.

CHAPTER IX

A STAR-SPANGLED BANNER

"The winter sunset fronts the North,
The light deserts the quiet sky,
From their far gates how silently
The stars of evening tremble forth!

"*Time*, to thy sight what peace they share
On Night's inviolable breast!
Remote in solitudes of rest,
Afar from human change or care.

"*Eternity*, unto thine eyes
In war's unrest their legions surge,
Foam of the cosmic tides that urge
The battle of contending skies."
— *George Sterling*, "The Testimony of the Suns."

STAR MAGNITUDES

"One star differeth from another star in glory." — I *Cor*. xv, 41.

THE stars are at such vast distances from us that in spite of the enormous sizes of some of them they all appear as mere points of light. This is true even with the most powerful telescope in existence. Only one star in the heavens is near enough to show a measurable disc, and that is the one which rules our own system under the names of Helios, Shemish, Baldur, Father Sol, the Sun of Righteousness, and a thousand other suggestive names.

But this does not mean that the stars all look alike, either with the naked eye or with the telescope. There are stars of almost all colours, and even those which appear to be of the same colour differ enormously in brilliancy. Sirius scintillates in the sky like a sparkling jewel, and glares down the telescope

tube like a little sun, so that he is better examined with a dark glass. A few other stars are not far behind in brilliancy. Large numbers are fairly bright, while swarms of them are comparatively inconspicuous. Still larger numbers are just visible to the naked eye, and the telescope reveals them in multitudes that no man can number. Yet no two of them send us exactly the same amount or quality of light.

It has been found convenient to classify the stars according to their brilliancy. At first the classification was rude, but of late years they have been sorted out with considerable accuracy. They are divided into a number of *magnitudes*, a star of one magnitude being 2½ times as bright as one of the magnitude below it.[1]

Thus a star of the *first* magnitude sends us 100 times as much light as one of the *sixth* magnitude, which is the faintest star visible without a telescope. And that is 100 times as bright as one of the *eleventh* magnitude, which in its turn is 100 times as bright as one of the *sixteenth*. This rule applies to all magnitudes. Taking Aldebaran as a standard star of the *first* magnitude, the North Pole Star belongs to the second, and the brightest star of the Pleiades to the *third*. The rest of the bright stars in the same group belong to the *fourth*. The faintest stars usually seen belong to the *fifth*, and those just visible by direct vision on very clear nights are of the *sixth* magnitude. The *seventh* magnitude stars can just be glimpsed by oblique vision, by unusually keen eyes, on exceptionally clear occasions.

There are a few stars brighter than Aldebaran, and these are sorted out in the same way, with the numbers reversed and the *minus* sign (—) placed in front of them, instead of the plus sign (+), which is sometimes used to denote the regular magnitudes. Thus one magnitude brighter than the first is denoted as (0), the next (—1), and so on. On this plan Sirius is denoted by the sign (—1.4), his brilliancy being 9.1 times greater than that of Aldebaran. And our Sun is a star of the magnitude —26.4,

[1] More exactly, 2.512.

his apparent brilliancy being about 90,000,000,000 times greater than that of Aldebaran.

It must be understood that the magnitude of a star does not denote its real size, or its weight, or the actual amount of light given off by it, or its distance from us. It merely denotes the amount of light we receive from it, and this depends on a combination of these factors, which are unknown to us in the vast majority of cases. For example, Canopus, which is the second brightest star in the heavens, is at an immeasurable distance from us, and must therefore be many thousands of times larger and brighter than our Sun. And some of the fainter stars visible to the telescope *may be* even larger than Canopus. On the other hand, some fairly brilliant stars are smaller even than our Sun, their distances from us being comparatively small, as stellar distances go.

For this reason the actual and apparent motions of the stars form a better guide to their distance, size, and actual brilliancy than do their magnitudes. We have an example of this in the star known as 61 Cygni, which is nearer to us than Sirius, although it is nearly seven magnitudes smaller and sends us nearly 600 times less light.

The number of visible stars has been already dealt with. It may, however, be interesting to know that there are about 50 stars of the second magnitude (from 1.6 to 2.4), and about one third that number of larger ones. Also that, from this down, each magnitude has about three times as many as the one above it. To the fourteenth magnitude (14.5) this would give 200,000,000, stars. With the fainter stars, however, the increase in numbers appears to be less rapid. The faintest stars visible to the eye in the great Lick telescope are of about the seventeenth magnitude.

ACTUAL BRILLIANCY OF VISIBLE STARS

The actual magnitudes of the stars may be considered from three distinct standpoints,—(1) Mass or Weight; (2) Size; (3) Brilliancy. We will here consider the brilliancy alone,

as comparatively little is at present known of the other two factors.

It must be remembered that stars which now give out little or no radiant energy are *not necessarily small.* Some of the largest suns in the Universe are feeble from extreme old age, while others are dead and cold, waiting patiently for the resurrection that comes through collision.

If the stars were all at the same distance from us, their actual brilliancy would be proportionate to their apparent magnitudes, and could therefore be easily found. On the other hand, if they were alike in actual brilliancy, we could estimate their distances from us by that alone.

As it is, however, with varying distances and sizes, the problem is a difficult one, and will probably never be solved except in the case of the nearer stars. I can give here only a few illustrations of what has been ascertained concerning the radiant energy of the stars.

Let us first consider what we may reasonably expect to find, and then compare our expectations with the results actually attained.

Take a certain distance, A L, and divide it into 11 regularly increasing intervals. Call these shorter distances B, C, D, etc.

Let us suppose that we are at A, and that there are 10 stars at the distance B. The actual brilliancy of these stars we may suppose to vary regularly, so that (from A) the largest appears equal to Sirius, and the smallest is just visible. If there be a similar set at each of the other distances, only 9 of those at C will be visible. Of those at D only 8 will be seen. And so on. Those which become invisible will of course be the smallest, but, as the others will appear smaller on account of the greater distance, the effect will be as though the largest were dropped. Beyond the distance K all will be invisible. Out of the 110 stars only 55 (one half) will be visible to us. We may expect, therefore, to find all sizes of stars among those nearest to us, while at the limit of visibility only the very largest will be visible, and they will appear very faint. For every star visible

there will be at least one invisible. This reasoning may be applied to telescopic stars as well as to visible ones.

First Step.—It is found, however, that there are no very large stars among those which are near to our System. The largest, both actually and apparently, is Sirius, which equals about 30 suns like ours. Procyon, Altair, and Alpha Centauri are also brighter than our Sun. The fifth-magnitude star known as 61 Cygni is small, and some of the binaries and multiple systems contain stars which give out hundreds and thousands of times less light than our Sun.

Second Step.—If we examine those which are very much farther away, but are still at a measurable distance from us, we find stars which have much more actual brilliancy than any of the nearest stars. And some of them, in spite of their great distances, are equal in apparent brilliancy to any of the nearest stars, with the single exception of Sirius. Those known as Arcturus, Regulus, Antares, and Gamma Cassiopeiæ, are each of them about equal in brilliancy to 1,000 suns like ours, rolled into one huge globe.

Third Step.—Among those which are at absolutely immeasurable distances from us we should not expect to find any stars equal in apparent magnitude to those which are so much closer to us. But here we meet with another surprise. For some of them are among the brightest stars in the heavens. They include, indeed, the second brightest star in the sky. Rigel, Canopus, and Arided are each of them many thousands of times larger and more brilliant than our Sun. In fact they are so large and brilliant that they exceed our Sun as much as it exceeds the planets which yield to its authority. They are so enormous that the mind cannot grasp their immensity. They may be the centres of systems of a higher order than ours, with mighty suns for planets, huge planets for satellites, and perhaps secondary satellites revolving around the primary ones.

Yet, for all we know to the contrary, some of the faint stars that fill the back-space of sky may exceed them as much as they exceed our Sun.

We have now taken three huge steps into the visible Universe, and at each step have found larger suns than we had come across before. And the fact that some of those that are at an immeasurably great distance from us are quite brilliant when seen from the Earth shows that several more such steps will have to be taken before we get beyond the great mass of fairly visible stars. This is true of those seen without the aid of the telescope, and it is much more true of telescopic stars.

DARK SUNS AND PLANETS

It has been already mentioned that some stars are not now luminous, their heat having radiated into space and left them dark and cold. There is some reason to believe that the Universe is crowded with these dead and dying suns, and that they are in fact vastly more numerous than the living ones. Besides these, there are the planets which probably swarm around each and every star, living and dead. Our own star has countless millions of such bodies revolving around it. Probably about a thousand of these are large enough and near enough to be detected by our telescopes, the smallest one visible (a satellite of Mars) being about seven miles thick. All the rest are too small or too distant to be seen by us. The only evidence we have of their existence is that they occasionally run up against our atmosphere, and are turned to flaming gas by the friction. Sometimes fragments of them reach the Earth's surface in a solid state, unaltered except at the original surface, which is vitrified by the heat.

VARIABLE STARS

While sorting out the stars according to their magnitudes, astronomers have discovered that large numbers of them vary in brightness at different times. They are therefore called "variables," to distinguish them from those which give out a steady unfluctuating light.

REGULAR (SHORT-PERIOD) VARIABLES

Algol Variables. — Some of these variables are periodic and regular in their changes. For example, Algol, which is usually of the 2.3 magnitude, fades every three days to the 3.5 magnitude, and recovers its normal brightness in a few hours. The spectroscope shows that between these minima it is alternately approaching and receding from us.

It is evident that in this case there are two stars revolving around their common centre of gravity, but that one of them is smaller and gives out little or no light. When it passes between us and Algol it partly eclipses the latter.

The period of revolution (three days), and the speed at which Algol moves to and from us, show that they are about 3,000,000 miles apart. The invisible companion appears to be about the size of our Sun, and Algol larger. But their masses, taken together, are probably less than half that of our Sun alone.[1]

Spectroscopic Double Stars. — Beta Lyræ is also a periodic variable, with partial eclipses every 6½ days. But in this case only the *alternate* minima are equal. The spectroscope shows the usual spectral lines to be *doubled.* There appear to be two unequal self-luminous stars revolving around each other, about 30,000,000 miles apart.

It is obvious that these two classes of variables, which are both regular in their fluctuations, are only apparently variable, through change of position. Their actual brilliancy remains the same. Most of them are white stars.

Stars below a certain magnitude cannot be satisfactorily examined spectroscopically, on account of the faintness of their spectra. Among the stars which have been so examined, about one in seven shows some inequality of radial motion, due to large invisible companions.

IRREGULAR (LONG-PERIOD) VARIABLES

Mira Ceti Variables. — Other variable stars (which are generally red) differ from the above in being irregular, both as

[1] One variable of this type has a period of only 4 hours.

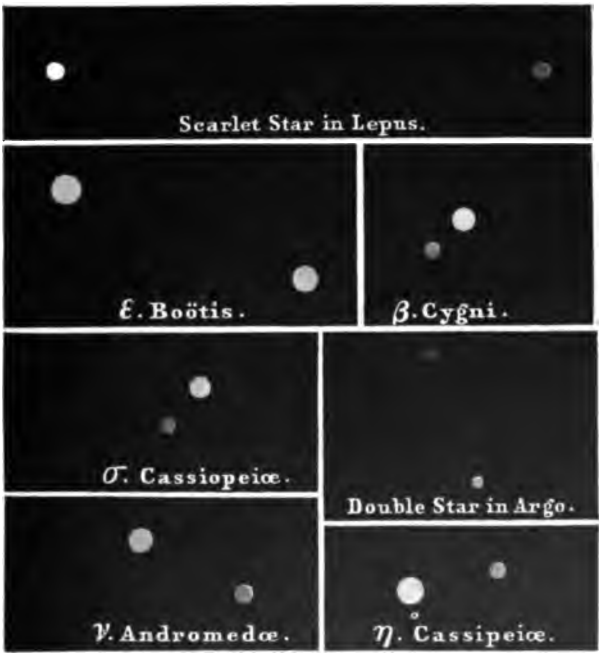


Fig. 59. — Coloured Double Stars

to *time* and *brilliancy* of *maxima* and of *minima*. Mira Ceti, for example, has a *maximum* varying from the second to the fifth magnitude, and a *minimum* varying from the eighth to the ninth magnitude. Its period also varies irregularly, being usually about eleven months.

The cause of such irregular fluctuations must be violent physical and chemical reactions such as take place on all large cooling bodies at certain critical temperatures. Even our Earth has passed through such crises in the past, and our Sun has slight spasms every eleven years from the same cause. Some day, when chemical compounds are formed on the cooling surface of the Sun, these fluctuations will be vastly greater than they are now.

NEW STARS

> "Vague on the night the mist we mark
> That tells where met the random suns." — *G. Sterling.*

Allied to these irregular long-period variables are the *new stars* which occasionally flash out in a hitherto vacant part of the sky, attain a maximum brilliancy in a few days, and then slowly die out again. These either disappear altogether or remain as telescopic stars. The *New Star in Perseus* is a familiar example of this class. Inside of five days it increased from telescopic invisibility to be the brightest star in the Northern Hemisphere (magnitude 0). It then faded gradually away, and in a few months became invisible to the naked eye.

While this star was increasing in brilliancy, the spectroscope showed an almost continuous spectrum, like that of other stars (Class III). But bright and dark bands gradually appeared in it (Class IV), and it ended by resembling the spectra of the true nebulæ (Class II).

This star's sudden appearance was not due to its coming toward us out of the depths of space. It was probably caused by a sudden and stupendous discharge of light and heat from a previously existing star or stars. Such an outburst may be produced in several ways.

For example: (1) two stars or planets may come into more or less direct collision, and spread out rapidly into a huge nebula of flaming gas. This will cool down in a short time to the temperature of space. Or (2) the colliding stars may strike a glancing blow and cut slices out of each other. In this case the slices alone will turn to gas, while the wounded stars will enter into partnership, revolving around their common centre of gravity. Or (3), the stars may not strike, but pass so close to one another that their solid crusts are rent asunder by tidal action, exposing the molten interior of one or both of them. Or (4), a dark star may, in the course of its wanderings, dash through an immense swarm of "pocket planets," commonly known as meteoric bodies. Such a collision will turn the meteorites into gas, and, if they are numerous enough, their dissipation will cause a temporary brilliancy like that observed. Or (5), a single cooling body may reach one of its "critical" periods, and flare up from sudden physical or chemical reactions, like those attributed to Mira Ceti, only more severe.

Collisions and minor interferences between all kinds of heavenly bodies must, in the very nature of things, take place now and then, seeing what multitudes of suns and worlds are hurtling through space, in all directions, without any one on board to guide them. And at the same time collisions appear to be necessary to prevent the Universe from dying of old age. The dead or dying hulks collide, turn to gaseous nebulæ, and start afresh to form new systems of suns and worlds.

DOUBLE AND MULTIPLE STARS

"Those double stars
Whereof the one more bright
Is circled by the other." — *Tennyson.*

In dealing with periodically variable stars it was shown that they are really *double-star systems* with orbits turned edgeways to us. There are immense numbers of similar systems which do not happen to be so situated, and are therefore not recognisable as "doubles" by the spectroscope. Some of them, however,

are so near to us, or have such large orbits, that the telescope itself enables us to detect their "duplicity" and follow their motions. There are over 10,000 double stars now known. In about fifty cases the time of mutual revolution has been determined with some certainty. The periods vary from 5.7 years[1] (the shortest telescopically visible) to 1,500 years. Many binaries take thousands of years to complete a revolution, and their motions have not been followed long enough to fix their orbits and periods.

Those dual systems of suns which started as partners not by direct collision, but by tidal division, are twins, their gaseous contents having, at first, the same heat and condition. It takes longer for a large mass to condense into a sun, and then cool off and die of old age, than it does for a smaller one. Therefore the larger of the two bodies is relatively younger than its companion, and the centre of brilliancy of its spectrum should be nearer to the violet end. Dual systems which started in other ways would not necessarily have this spectral peculiarity.

For some unexplained reason there is much more variety of colour in double stars than in single ones. They are sometimes of a green, blue, or violet colour (see Figure 59).

In some cases there are more than two suns in the same system. The North Pole Star, for example, has two companions large enough to be classed as suns, though one of them has ceased to give out any appreciable light and heat.

There appears to be every gradation of solar systems visible to the telescope. They vary from simple ones like ours, to highly complex star-clusters, like the one in the constellation of Hercules. This has over 6,000 visible suns, and appears to be surrounded by long spirally radiating wisps of nebulous matter in which other stars are entangled.

SOLAR DRIFT.

It has long been known that some of the nearer stars are not absolutely fixed, but are slowly changing their positions in

[1] Delta Equulei.

the heavens. And the spectroscope has told us that, while some stars are coming nearer to us, others are retreating. From the nature of the evidence we may safely assume that all stars are in motion, and that our Sun partakes in this stellar drift, carrying its planets along with it.

If our sun be assumed to be motionless, then the observed motion of a star must be real, due to its own drift through space. But if our System is also adrift, the observed motion of a star may be only apparent, due to our own change of place. Or it may be partly real and partly apparent.

It is obvious that, if our Sun is drifting in one direction (carrying us along with it), the stars toward which it is drifting will appear to open out or separate, while those from which it is retreating will appear to close up. At the same time those which we are passing will appear to drift backward.

Now the telescope shows that all three of these peculiarities are actually taking place. The stars around Vega, in the constellation of the Lyre, are gradually separating from one another, those on the opposite side of the heavens are as gradually closing up, and those at right angles to this line of march are drifting backward.

The conclusion is obvious. The motions of the stars are, at least in part, only apparent. Our whole System is drifting in the direction of Vega.

Lest we should have made a mistake, let us inquire of the tele-spectroscope, and find out which stars are approaching us and which are receding.

According to the spectroscope and spectrograph, the majority of the stars about Lyra are approaching us at the average speed of about 12½ miles a second. And the majority of stars opposite that constellation are receding from us at about the same rate. In the circle of the heavens between these two points there is no decided motion either to or from us.

We thus see that two absolutely independent sets of evidence both point to the same conclusion. Our Sun is drifting toward

Fig. 60. — Star-cluster in Hercules

Lick photograph.

Vega at the rate of 12½ miles a second, and all the planets share in the "solar drift."

On account of this solar drift, the orbit of the Earth, instead of being an ellipse, is really of a corkscrew shape, the axis of the "corkscrew" being in the direction of the constellation Lyra.[1]

STELLAR DRIFT

After allowing for the *apparent* motions of the stars, due to our own drift, there remain certain *real* motions of the stars, due to their own drift.

For instance, the telescope shows that the star known as 1,830 Groombridge is moving steadily along at the rate of over 200 miles a second. Some other stars have motions as real, though not as rapid. The spectroscope shows that some stars are actually approaching us, while others are as actually receding from us.

In some cases a number of stars are drifting along together, showing that they form a family group. The Pleiades form a familiar example of this social drift through space.

[1] The Cluster of Hercules is not very far away from the part of the sky which we are approaching. It is possible that our System may form a distant part of one of its encircling wisps of star-strewn nebulous matter. In this case we may eventually be drawn into the cluster.

8

CHAPTER X

CONSTRUCTION OF THE UNIVERSE

"Secondly, . . . what is the arrangement of the stars in space? Especially, what is the relation of the Galaxy to the other stars? In what senses, if any, can the stars be said to form a permanent system? Do the stars which form the Milky Way belong to a different system from the other stars, or are the latter a part of one universal system?" —*Prof. Simon Newcomb.*

DISTRIBUTION OF STARS

IN the stellar population of the visible Universe there are very great differences of distribution. Although it would be difficult to point a powerful telescope to any part of the sky and find the field of view absolutely bare of stars or nebulæ, yet in some directions they are very much more scarce than in others. In fact the visible inhabitants of space are as unevenly distributed as is the human population of Usona. There are belts of sky that are swarming with cities, towns, and villages of social stars, and have the intervening spaces well peopled with more independent families. And there are large tracts of sky that are comparatively thinly inhabited with visible suns. Some of the star-clusters are almost as crowded as are our cities. In some of the thickly settled tracts nearly all the stars are well developed, while in others large numbers of the inhabitants are in a nebulous embryonic stage.

ALL SORTS AND CONDITIONS OF SUNS

In that part of the Universe which is at present visible from our Earth, there are many different structures and styles of architecture. And all stages of construction and development are represented. There are systems that appear to be still in the throes of birth; systems in young and vigorous growth;

Fig. 61. — Part of the Milky Way in Sagittarius

Photographed by Barnard, at Lick.

Fig. 62. — A Rope-like Nebula in Cygnus

Keeler at Lick.

Some outside influence appears to have torn it asunder and left its tattered fragments streaming through space.

systems in the strength and pride of maturity; systems that are tottering toward the grave; and systems that are cold in death and waiting for the resurrection that will surely come.

THE CONSTELLATIONS

The stars that are visible to the naked eye have long been divided up by man, for his own convenience, instruction, and amusement, into groups or *constellations.* About 48 of these are extremely ancient, and the rest are quite modern.

The ancient constellations appear to have had a priestly origin and an important religious significance. The stars were divided into groups, each of which was supposed to form a picture of some person, animal, or inanimate object. The 48 constellations contained 54 figures, which formed a huge sky-picture whose mystic meaning has long been lost sight of by the multitude.

These fanciful figures appear to have been invented by a people who lived south or southeast of the Caspian Sea, nearly 5,000 years ago. As the stars near the South Pole were invisible from their part of the world, they naturally left that section of the sky unfigured. The size of the circle which was left blank shows us that the constellation-makers lived about 39° north of the Equator. And the animals, etc., which they pictured in the sky, tell us their longitude on the earth; for they naturally depicted the animals with which they were acquainted, and none others. Even the animal monstrosities were combinations of familiar animals.

Owing to what is known as the Precession of the Equinoxes (described in Chapter XII), this circular blank space does not now centre at the South Pole, and the amount of its drift tells us that the constellations were completed about 2800 B.C.

The first groups of stars to be pictured out were evidently the twelve Signs of the Zodiac, likewise known as the "Mansions of the Sun." The picture-makers were astronomers of no mean ability. They had already determined the length of the year

with some degree of accuracy. They had recognised the fact that the stars are in the sky during the daytime, though they cannot then be seen under ordinary circumstances. They had even traced out the annual path of the Sun among the stars. This was a remarkable achievement which few of us would have the patience and ingenuity to accomplish unaided. To do it they must have rigged up some sort of equatorial mounting, with a number of pointers directed to the most prominent stars.

To enable them to ascertain the Sun's position in this path, or Ecliptic, all the year round, they divided up the neighbouring stars into twelve constellations. This made it easier to keep track of the months, seasons, and years. It also enabled them to find the four critical days in which the seasons culminated. Being Sun-worshippers, like nearly all the nations of antiquity, they were very anxious to ascertain the exact date of the sabbaths, new moons, equinoxes, and solstices; for otherwise they could not time their feasts, fasts, and sacrifices so as to have them credited in the heavenly ledger. They regarded the Sun as a Great Spirit labouring for the good of mankind, and fighting the powers of cold and darkness with varying success. Each summer he got the upper hand, but in the winter he lost his strength, like his Semitic prototype, Samson, when he was shorn of his flowing locks. As the very existence of the human race depended on the Sun-God's success, the struggle was watched with never-flagging interest and anxiety.

The year was then reckoned to begin in the spring, at the time when the days and nights were equal. The Sun-God was then in the centre of a group of stars which they pictured out as a Bull (*Taurus*).[1] At the longest day their God was in the centre of a group which they named the Lion (*Leo*). At the autumn equinox he was in the centre of a group which they imagined to represent a Scorpion (*Scorpio*). And on the shortest day in winter he was in the midst of a group which they called the Water-Carrier (*Aquarius*).

[1] Subsequent generations long inherited the tradition that each year was opened by a bull with golden horns.

Fig. 63. — Spiral Nebula in Triangulum

Lick photograph.

These significant symbols became famous in mythology, and are several times mentioned in the Hebrew Bible and early Christian writings. The brightest star in or near each of the four groups has been known ever since as a "royal" star, though its significance was lost when the Precession of the Equinoxes dethroned the celestial Bull and set the heavenly Ram in the place of honour. These royal stars were *Aldebaran*, *Regulus* *Antares*, and *Fomalhaut*.

The Zodiacal groups having been satisfactorily marked out, the northern stars were made into a great winged Dragon (*Draco*), which was supposed to guard the pole of the heavens.[1] The rest of the constellations were then figured off in other parts of the sky. They were all connected together, each figure forming a portion of the same great mythological sky picture. As a rule they were all upright when on the meridian, either north or south.[2]

The picture-makers of 2800 B. C., looking south at midnight at the spring equinox, imagined a huge man in the sky, crushing a scorpion with his left foot, and strangling an enormous serpent which was coiled around his body. The same observers, on turning to the north, pictured a second man, kneeling on one knee, and pressing the head of a winged dragon with the other foot.[3] The stars which were faintly visible above the southern horizon were afterward worked into the picture, and the knowledge of it was handed down, from generation to generation, as a divine revelation, to change or add to which would be sacrilege.

These picture-makers appear to have domesticated cattle, sheep, goats, dogs, and horses. They hunted bears, lions, and

[1] In after years the Precession of the Equinoxes made this winged dragon slip off the pole of the heavens. He was then said to have been overcome by the stalwart Michael and thrown into a pit that had no bottom. One rather lurid writer tells us that "his tail drew the third part of the stars of heaven, and did cast them to the Earth."

[2] See the Constellation Chart at the end of this book.

[3] The head of this winged dragon was then turned threateningly toward the man, and had two bright stars for eyes. Its wings have since then been cut off, in order to make room for other constellations. Its head has also been turned around, for the same reason, so that its fierce basilisk stare has been lost.

hares, using bows and arrows, as well as spears. They do not appear to have been acquainted with the tiger, elephant, camel, hippopotamus, or crocodile. To their north lay a sea, and they were familiar with ships and with sea-monsters. They sacrificed on altars; knew the stories of the Fall and of the Deluge, and probably devised many of the constellations to keep record of them.

These constellations became known to the Greeks. They are described in a poem of Aratus (260 B. C.), and are mentioned in the star-catalogue of Ptolemy (150 A. D.). In modern times their religious significance has been lost. From time to time their irregular and arbitrary boundaries have been changed, and a number of other groups have been formed, to fill in the vacant places. About 90 constellations are now recognised.[1]

Most of the larger stars are known by names which were given them by the Arab astronomers. Large numbers are distinguished by the genitive form of the name of the constellation in which they occur, with a Greek letter prefixed to it. Many thousands are known only by numbers in certain star-catalogues. The great majority of telescopic stars have no names at all.

It is not necessary to describe the constellations here, as they are best studied by night, under the blue heavens, with an occasional reference to a star atlas. The four star charts given at the end of the book will be a help to beginners who live in the Northern Hemisphere. One of them gives the North Polar heavens, and the other three include all the Equatorial constellations. In order to avoid confusion, no names or divisions are marked on these charts, but each one is accompanied by a key, giving all necessary particulars.

The first of the Equatorial Charts is intended to be used in the spring (from December to March), the second in the sum-

[1] Those interested in the ancient constellations should read an article by the late Richard A. Proctor, in his "Myths and Marvels of Astronomy," and another by E. W. Maunder (F.R.A.S.), entitled "The Oldest Picture Book of All," in the "Nineteenth Century Magazine" for September, 1900.

FIG. 64. — THE GREAT NEBULA IN ANDROMEDA

mer (from April to July), and the third in the autumn (from August to November). The Polar Chart can be used all the year round.

In order to understand these charts, the learner should go outside on a clear starlight evening, about nine o'clock, and seat himself in a rocking-chair, facing the south. If he can tilt the chair back against some trustworthy support, it will be an advantage, as he may otherwise see the wrong kind of stars. A dark lantern will be an assistance, to enable him to see the charts and keys at intervals.

Let the beginner now select the Equatorial Chart which is suitable for the time of the year. At the foot of the chart he will find a number of dates. Selecting the date which comes nearest to that of his observation, he will find that the stars represented above it agree with those in the heavens in front of him, from the horizon to the point overhead.

When the beginner wishes to identify the stars which are farther north than the point overhead, he should take the Polar Chart and turn it till the proper date is at the foot of the chart. He can then lean well back in his chair, when he will be able to recognise the resemblance between the brightest of the stars above him and those represented on the chart. With the help of the proper key the names of the stars and constellations can be gradually and pleasantly acquired.

A good way to make a beginning is to get acquainted with the names and positions of the brighter stars on clear evenings, to divide them up into squares, triangles, etc., and then to fill in with the fainter ones. After having done this in the Polar regions, they can be connected with stars farther south, giving particular attention to those on or near the Equator and Ecliptic.[1]

[1] The Equator can easily be found by fastening a stick or pointer to the top of a fence, so that it points to the northwestern star in the Band of Orion, when it is due south. All the Equatorial stars will occupy the same position when they come to the local meridian. The Ecliptic can easily be found (approximately) by noting the position of the Moon among the stars every night that it is visible. The large planets are also on or near the Ecliptic. To prevent their being mistaken for stars it should be remembered that they do not twinkle, but shine with

In the course of a year the greater part of the heavens will thus come under observation without the necessity of staying up late at night.[1]

Most of the stars in these constellations are only visually connected, so that an observer in a distant solar system would find them altogether differently arranged. There are many natural groupings, however, like that known as the Pleiades, and another including several of the brighter stars in the constellation of the Great Bear. Such natural groups are being discovered by the fact that the stars composing them are drifting in the same direction and at the same speed.

Most of the telescopic star-clusters are evidently family groups, as are also the thousands of double, treble, and quadruple stars which revolve around their common centres of gravity.

THE GALAXY

"A broad and ample road whose dust is gold,
And pavement stars." — *Milton.*

The largest and most important structure in the visible Universe is that nebulous haze of invisible suns which is known as the *Via Lactea*, the *Galaxy*, or the *Milky Way*. In fact, if the Universe were no larger than the visible part of it, we might almost say that the Universe itself consisted of the Milky Way and its appendages.

With the naked eye the Galaxy forms the most conspicuous object of the midnight heavens. It is an irregular hazy ring crossing the celestial sphere in a great circle. This circle is like that containing the Signs of the Zodiac, but is very much more tipped up with reference to the equator. A telescope of

a steady unflinching light. It will soon be found that they gradually change their positions among the stars that lie near the Ecliptic.

[1] "Astronomy without a Telescope," by E. W. Maunder, F.R.A.S., will be found to make the subject more interesting. This may be followed by the study of "Astronomy with an Opera Glass," and "The Pleasures of the Telescope," both by Garrett P. Serviss.

Fig. 65. — A Spiral Nebula Seen Edgeways (H. V. 41 in Canes Venatici)

Lick photograph.

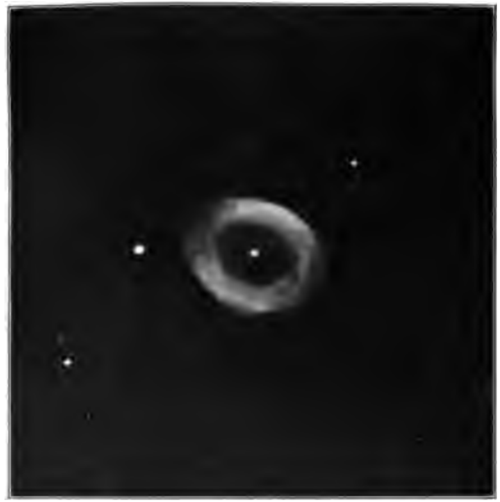


Fig. 66. — The Ring Nebula in Lyra

Gaseous. Signs of a spiral structure. Interior of ring filled with faint nebulosity. Faint star in centre. About 33 light years from us. Diameter of "ring" 14 times that of Neptune's orbit. The only nebula whose distance and dimensions are known.

moderate power shows that it consists of a "blinding snow-storm" of suns and star-clusters.

This Milky Way was formerly considered to form a kind of irregular disc or "grindstone," with our Solar System not very far from its centre. More accurate observations, however, have caused this theory to be discarded. It is now believed to consist of long spiral wisps or serpent-like streams of nebulous haze, *of more or less circular section*, and considerably distorted by projection. In one place the main stream splits in two, but finally comes together again. This split portion has a number of narrow nebulous channels crossing the dark interval which separates them, and dividing it into irregular islands, or "coal-sacks." If we were on one side of this Milky Way, instead of being inside it, we should probably see it as a vast ring-like spiral nebula, with its centre of rotation still comparatively empty.

If the observer is favourably situated, nearly all of the Milky Way may be seen from one station in the course of a long winter night. Such an observation will soon show that, although very irregular, these "flowing robes of infinite space" form, on the whole, a nearly complete girdle around our part of the Universe.

With a telescope it is easily seen that the Galaxy consists of an innumerable host of telescopic stars, promiscuously distributed, with thicker clusters or aggregations here and there (see Figures 47, 48, and 61). Even the naked-eye stars (with the exception of the nearest) are found to be most numerous in and around the Milky Way, and to thin out gradually as we approach its poles on either side. The same is true of the stellar nebulæ. The entire visible system probably resembles a watch in shape, slowly rotating on its axis, and condensing into a flat spiral disc.

THE NEBULÆ

While it is found that the stars and stellar nebulæ are most numerous near the Milky Way, it is rather startling to find that with the Gaseous Nebulæ the reverse is true. There are

very few of them in or near the Milky Way, and they increase in numbers toward its poles.

The Magellanic Clouds, in the Southern Hemisphere, greatly resemble the Milky Way in appearance; but, instead of being composed of stars and stellar nebulæ, they consist of stars and gaseous nebulæ.

Some nebulæ are diffuse and sprawling, as though the central attraction was not strong enough to draw them together or had been overpowered by some outside influence. One of them has been traced along the starry sphere for a length of 8 degrees. Supposing that its distance from us is only two million times the Sun's distance (and it can hardly be less), it must be as long as from here to the nearest star. Though many of the gaseous nebulæ are of enormous thickness, they all appear to be transparent.

The late Professor Keeler, a short time before his death, found that the telescopic camera showed twenty times as many nebulæ as the telescope alone. The number within the range of the photographic telescope is now put at 120,000 or more, and the majority of them are more or less spiral, like those represented in Figures 63 and 85.

The Great Nebula in Andromeda has a condensed nucleus (giving a continuous spectrum) surrounded by a swirl of nebulous matter. In fact, it looks not unlike the planet Saturn surrounded by its rings (see Figure 64). It is, however, immensely larger than our entire Solar System, and is probably a galaxy of suns.

When a spiral nebula is turned edgeways to us, it is not recognisable as a spiral, but has a more or less lenticular shape (see Figure 65). The remarkable Ring Nebula in Lyra resembles in telescopic appearance one of the familiar vortex rings which occasionally rise from the smoke-stack of a steam-engine. Like most of the ring-nebulæ, it has a faint star in its centre. But photographs recently taken by Professor Schaeberli at Ann Arbor, Michigan, show that a two-branched spiral originates at and surrounds this central star. The visible nebu-

Fig. 67. — The Trifid Nebula in Sagittarius

Composed of glowing gas. The rifts were probably caused by stars drifting through body of nebula.

lous ring is the most prominent part of this double spiral (see Figure 66).

Other nebulæ have very irregular outlines, at some places clean cut, and elsewhere fading gradually away. Some are split up by sharp fractures, as though they had been torn asunder by some wandering star drifting through them. Such is the Trifid Nebula in Sagittarius (see Figure 67). The Great Nebula in Orion also has some of these peculiarities, and has several nebulous stars connected with it. Its present irregular outlines may be partly due to the disrupting influence of these stars, or it is possible that the neighbouring nebula may have collided with it. Seen through a powerful telescope, it forms one of the most magnificent objects in the heavens. Its real size is so enormous that the mind cannot realise its vastness. It has been estimated that if a million discs as large as the orbit of Neptune were placed in front of the nebula, they would not be sufficient to hide it from us. The spectroscope shows that the matter composing it is in the form of gas so diffuse as to be almost a vacuum (see Figure 68).

It was formerly supposed that all nebulæ are at an intense heat, causing the peculiar glow which makes them visible to us. It seems probable, however, that the more diffuse of them are at the temperature of space (—230° F.), and that their light is an electrical phenomenon due to a rain of negatively charged particles driven off from the stars (in the form of coronæ) by the repulsive action of light. This would explain the simple nature of their spectra, as the glow would be chiefly confined to the surface, where the lighter gases, like hydrogen and helium, collect.

UNSOLVABLE PROBLEMS

Although a great many facts bearing on the distribution and relationships of the visible stars and nebulæ have been discovered in the last few years, we are not yet in a position to give a satisfactory answer to the questions asked in the quotation at the beginning of this chapter. At present we can only say, with the late Richard A. Proctor:

"The sidereal system is altogether more complicated and more varied in structure than has hitherto been supposed: in the same region of the stellar depths co-exist stars of many orders of real magnitude; all the nebulæ, gaseous or stellar, planetary, ring-formed, elliptical, and spiral, exist within the limits of the sidereal system; and, lastly, the whole system is *alive* with movements the laws of which may one day be recognised, though at present they are too complex to be understood."

The Universe is so vast that a bird's-eye view of it cannot be obtained from a single standpoint, and though that standpoint is being swept along through the lofty corridors at a speed fifty times as great as that of a cannon-ball, the life of the human race is hardly long enough to profit by the change of position. We are like the man in the forest who said that he could not see the wood for the trees. Even in those parts where we imagine that we can see a limit to the celestial forest, we cannot be sure that it is not a mere clearing in the woods, or a gap between our forest and the next one. And the situation is complicated by the fact that the celestial trees are not anchored fast to a visible ground, but are drifting around in all directions, while we are prisoned on a conveyance whose movements we are utterly unable to control.

To use the simile of Sir Isaac Newton, we can learn something of the celestial pebbles that lie around us, but the great ocean is beyond. The *finite* cannot grasp the *infinite,* nor can the *ephemeron* comprehend the *eternal.* And if it could, what then?

FIG. 68. — GREAT NEBULA IN ORION

Lick photograph.

Irregular mass of glowing gases. Many millions of times larger than Solar System.
Irregularities possibly due to collision with neighbouring nebula.

CHAPTER XI

SOLAR ARCHITECTURE

"We know the Sun to be infinitely more complex in structure . . . than it was formerly supposed to be. . . . We have learned that . . . the glowing veil of air hides by day . . . the largest (though not the most massive) part of that Sun." — *Richard A. Proctor.*

THE individual construction of the stars themselves can best be found by studying our Sun and comparing its peculiarities with those of more distant suns. This comparison has led to the discovery that no two stars are at precisely the same stage of evolution.

INTERIOR OF SUN

Our Sun appears to be still gaseous with heat, from centre to circumference. But its constituent gases are so compressed by the attraction of its huge mass, that it is, on the average, denser than water. It has in fact the density of a liquid with the mobility of a gas. In other words, it is composed of glowing "gaseous-liquids," the central layers of which are extremely dense (for gases), while the outer layers are only moderately so.

The gaseous-liquid nature of the interior is shown by the average density of the Sun, which is 1.4 that of water. This is about what might be expected for a huge mass of intensely hot gas, but is far too small for solids or liquids, taking into consideration the fact that solar gravitation is more than 27 times as great as that of the Earth.

That the interior is not solid may also be seen from the fact that the surface heat is kept up by a continuous supply of hot material from below. This interior heat is actually due to the contraction or shrinkage of the outer layers of the Sun as they

cool off. The whole Sun may be said to boil, the hot gases forcing their way (explosively or otherwise) to the surface, cooling off somewhat, and then sinking. If the interior were solid, or if a solid crust were to form, this "boiling" circulation would cease, the heat would not be so free to rise, and the surface would lose its heat and become dark. Some day this will take place, and we shall then have to look for another source of heat, or get used to the intense cold of interstellar space.

This is the period referred to by George Sterling when he says:

"The Night inevitable waits
Till fails the insufficient Sun,
And darkness ends the toil begun
By Chaos and the morning Fates.

"And starward drifts the stricken world,
Lone in unalterable gloom,
Dead, with a Universe for tomb,
Dark, and to vaster darkness whirled."
— *The Testimony of the Suns.*

Judging from the Sun's outer characteristics, it is almost certain that there are no compound substances in its interior. It is even possible that the so-called elements themselves are dissociated, by the intense heat, into one primitive form of matter, which exists only in the gaseous-liquid state.

THE PHOTOSPHERE

The solar photosphere is a dazzlingly incandescent globular shell surrounding and concealing the main body of the Sun. It is indeed the only part of the Sun which is usually visible to us. It is composed of closely packed clouds of intensely hot metallic vapours.

These photospheric clouds are probably long and pillar-like, floating *upright* in the metallic atmosphere of permanent gases which surrounds the main body of the Sun. Under ordinary circumstances only the bright tops of these radial clouds are visible to us. As the spaces between them are comparatively

dark, the result is that the entire surface of the Sun has a granulated or mottled appearance when seen through a powerful telescope. It looks, indeed, like a piece of grey cloth stretched over a hoop, with rice-grains or snowflakes thickly scattered over it.

The particles composing these upright floating clouds probably rise (in a gaseous state) from the inconceivably hot interior of the Sun, and gradually cool off through expansion and outward radiation. At a certain elevation the diminished pressure and temperature cause them to condense into the brilliant vaporous clouds whose tops form the visible photosphere.

As the rising, cooling, and condensing processes go on all around the solar nucleus, there is probably a continuous deluge of white-hot metallic "rain" descending Sunward from the chilled summits of these radial luminous clouds.

It is possible that in the case of refractory elements like carbon, calcium, etc., the liquid drops "freeze" and descend in a "hailstorm" of genuine diamonds and solid metal shot. If this is so, it is evident that the falling "hail" will be remelted and vaporised as soon as it reaches a sufficiently hot layer of gases. The extraordinary brilliancy of the solar photosphere may be largely due to the clash of these diamonds and metallic shot, as they fall back in a continuous incandescent hailstorm onto the ascending gases beneath them.

FACULÆ AND SUN-SPOTS

The intense activity of internal physical action is sometimes indicated by the appearance of certain dark blotches on the otherwise fair face of the photosphere. These are commonly known as *Sun-spots*, and are usually surrounded by brilliant eruptive patches of piled-up photospheric clouds or *faculæ*.

The Sun-spots are more or less irregular black hollows which occasionally form in the cloudy photosphere on each side of the solar equator, and are seen to drift around as the Sun rotates on its axis (see Figure 24). They are most abundant at rather irregular intervals of about eleven years. At the beginning of

one of the Sun-spot periods the spots are some distance north and south of the Equator. Later on, the Sun-spot areas move nearer to it, so that the last spots seen, in one such period, are not far from the Equator.

The Sun-spots usually break out in the midst of a piled-up mass of brilliant *faculæ*. At first they appear as irregular black openings in the bright photosphere. They gradually increase in size and become more circular in outline. The lower ends of the long perpendicular clouds which (presumably) compose the surrounding photosphere gradually drift into the opening, so that the spot becomes a saucer-shaped depression. The black bottom of this saucer is known as the Sun-spot *nucleus*, and the semi-dark fringed sides form what is known as the *penumbra*.

The nucleus itself is sometimes 40,000 to 50,000 miles in diameter, the surrounding penumbra being occasionally 150,000 miles across.[1]

Sun-spots vary in depth from 500 to 2,000 miles, and are filled with cooler and therefore less luminous gases, which absorb the light from below. The blackness is only the result of contrast, for their gaseous contents are really hotter and brighter than molten steel. There appears to be a spiral uprush of hot gas all around the spot, with a descending current in the middle. They are evidently related to the cyclones, tornadoes, etc., in the temperate regions of our Earth. The surrounding penumbra consists of jets, swirls, and cataracts of luminous vapour surging into the abyss. Long plume-like "bridges" of superheated gas occasionally shoot out from the sides and cross the cavity, which is finally covered up by dazzling masses of faculæ (see Figures 25 and 69). When these brilliant inrushes of vapour are crossing the abyss, they produce an electrical activity which extends far out into space. On our Earth it produces the polar phenomena known as the Aurora, and causes powerful currents in all kinds of electrical apparatus. These latter are commonly known as electrical storms.

[1] If the great Sun-spot of 1858 had been 35 times larger, it would have covered the entire surface of the Sun, and practically put it out of business for the time, so far as illuminating and heating purposes are concerned.

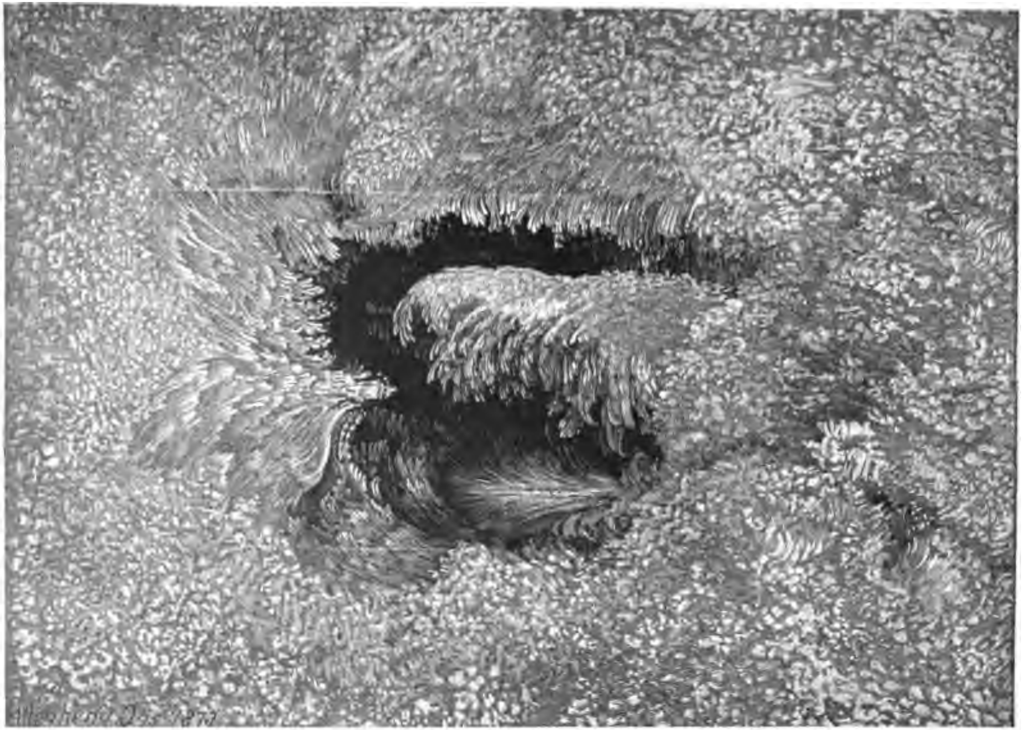


Fig. 69. — A Typical Sunspot

Drawn by Langley. (*From Langley's "New Astronomy," published by Messrs. Houghton, Mifflin & Co.*)

ROTATION

An examination of the time which it takes the spots and granulations of the photosphere to move across the disc as the Sun rotates shows that the clouds at a distance from the Equator take a longer time to complete a rotation than those on or near to the Equator. While the Equatorial granulations rotate in 25¼ days, the spots take more than a day longer to complete their rotation. And the granulations near the Poles take about 40 days to go once around. This shows the gaseous mobility of a great part, and probably of the entire mass, of the Sun.

THE CHROMOSPHERE

I have said that the dazzling white clouds which form the visible photosphere float in an atmosphere of uncondensed gases. This metallic atmosphere, or veil, is ruddy, but tolerably transparent. It extends 4,000 or 5,000 miles above the luminous clouds, and has a ragged storm-tossed surface (see Figure 27). It is known as the *chromosphere*, *sierra*, or *solar atmosphere*. The lower portion of it (about 500 miles thick) is known as the "reversing layer."[1] The spectroscope has shown that this lower and denser portion consists of metallic gases, with some non-metallic elements, all free and uncombined on account of the intense heat. The most abundant (or at least the most recognisable), are *hydrogen*, calcium, iron, manganese, nickel, and titanium. The following are also present: barium, *carbon*, chromium, cobalt, germanium, helium, magnesium, platinum, *silicon*, silver, sodium, and zinc. There is also strong evidence of the presence of aluminium, cadmium, copper, lead, molybdenum, *oxygen*, palladium, uranium, and vanadium.

In addition to these elements, there are lines indicating the existence of substances as yet unknown on Earth.

[1] This name is derived from the fact that a spectrum formed from its light *alone* has the usual dark solar absorption lines *reversed* into bright radiation lines. This "flash spectrum" can be obtained for only a few seconds at the beginning or end of a solar eclipse.

There are no signs of *chlorine, nitrogen,* gold, mercury, phosphorus, *sulphur,* and some other elements. This does not, however, prove that they are not present in other parts of the Sun.

The upper and thinner portion of the sierra does not contain the numerous metals found in its lower "reversing layer." It is composed of *hydrogen,* helium, and one or two other permanent gases.[1]

ERUPTIVE PROMINENCES (METALLIC FLAMES)

In the Sun-spot zones on either side of the Equator, immense *red jets* of glowing gas rise between the white clouds of the photosphere, pass through the sierric atmosphere, and extend many thousands of miles above it. They are known as *eruptive prominences* or *metallic flames* (see Frontispiece and Figures 26, 27, and 70). The highest one ever seen rose more than 350,000 miles above the general surface.

These red metallic flames are best seen when on the edge of the Sun. When they are on our side they are invisible with the telescope, but their upper surfaces can be photographed (at different elevations) with the aid of Professor Hale's spectroheliograph. In this position they are known as Eruptive Calcium Flocculi (see Figure 128).

These eruptive flames, or flocculi, consist chiefly of gaseous calcium, hydrogen, sodium, magnesium, and iron. They appear to be forced up by explosive physical changes below the photosphere, but their great elevation is probably due to the repulsive action of light on the small particles of which they consist.

CLOUD PROMINENCES (HYDROGEN FLAMES)

Above the sierra or chromosphere there are also to be seen huge *ruddy clouds* consisting of *hydrogen* and helium. When they are seen in profile, at the edge of the Sun, they are known as

[1] The non-metallic elements are here printed in italics.

cloud prominences or *hydrogen flames.* When they are on our side of the Sun, and are photographed from overhead by means of the spectroheliograph, they are called *hydrogen flocculi.*[1] They are not confined to latitudinal belts or zones, like the eruptive ones just mentioned, but are to be found over all parts of the Sun's surface. There does not seem to be any atmosphere for them to float in. Like the eruptive prominences, they appear to be composed of extremely small particles of matter, upborne by the repulsive action of the Sun's light.

FIG. 71. — A SOLAR "CLOUD" OF GLOWING HYDROGEN (PROFESSOR YOUNG)

About 100,000 miles long and 54,000 miles high. Notice the bright uprush below one end of it.

In 1871 Professor Young observed a hydrogen cloud about 100,000 miles long, with its summit about 54,000 miles above the sierra. It was connected with this latter by a number of vertical columns that looked like water-spouts (see Figure 71). Thirty-five minutes later the cloud had been blown to pieces by an eruption, and the fragments were scattered to a height of 207,000 miles (see Figure 72). They gradually faded away as they rose, leaving an eruptive prominence 50,000 miles in height (see Figure 73). The flame-like summit of this eruptive mass rolled over like a breaking wave (see Figure 74), and in a few minutes faded out of sight. These changes all took place in about two hours.

[1] For further particulars concerning the spectroheliograph and the latest results obtained with its aid, see an illustrated article by Professor Hale in the "Popular Science Monthly," for May, 1904.

THE CORONA

The white spherical cloud-surface of the Sun has now been described, and also the ruddy atmosphere and the two kinds of prominences which rise from it. But outside of all these there is a radiating halo of pearly light sometimes extending more than 2,000,000 miles in every direction (see Figures 26, 28, and 75). This is known as the *corona*. Like the eruptive prominences, it appears to start from volcanic outbursts; but, its particles being smaller, instead of being merely upheld by the radiant energy of the Sun, they are violently repelled, so that they stream forth continuously and pass away into outer space. When Sun-spots are numerous, the visible corona does not extend so far as when they are absent or scarce. The greatest development of the corona is over the Sun-spot zones north and south of the Equator. The rotation of the Sun causes the coronal streamers to bend in a plume-like manner. They are not so crowded together near the poles of the Sun, so that the polar streamers are very distinct (see Figure 29).

FIG. 72. — THE SAME REGION 35 MINUTES LATER (YOUNG)

Rising wisps of glowing hydrogen, reaching a height of 207,000 miles. The eruptive mass below is growing larger.

When the spectroscope is turned to this coronal halo it shows a continuous spectrum crossed by bright lines. The former

FIG. 70. — SOLAR "FLAMES" OR PROMINENCES

By Zoellner. (*From Comstock's "Text-book of Astronomy," published by Messrs. D. Appleton & Co.*)

FIG. 76. — THEORETICAL SECTION OF SOLAR PHOTOSPHERE

By Trouvelot.

Clouds of carbon, etc., floating in an atmosphere of metallic gases. Hot gases from interior forcing their way out. (*From Todd's "New Astronomy," published by The American Book Co.*)

indicates the presence of solid or liquid particles, and the bright lines are those of glowing hydrogen gas. There is also a bright green line due to an unknown gas which has been provisionally named "coronium." The atoms of these substances are so far apart that the corona is practically a vacuum.

FIG. 73.—THE SAME REGION 35 MINUTES LATER (YOUNG)

The uprush has developed into a mass of rolling and ever-changing "flame," 50,000 miles in height.

SOLAR ENERGY

As in the lime-light, or oxy-calcium lamp (used for magic lanterns, etc.), the brilliancy of the Sun's photosphere is largely due to incandescent calcium. The intense bluish-white light of this hollow cloudy sphere forces its way through the ruddy transparent atmosphere and prominences. In doing so it loses much of its intensity and becomes slightly yellow. It passes through the coronal streamers with but little loss, and spreads out evenly in all directions.

FIG. 74.—THE SAME, 15 MINUTES LATER (YOUNG)

In half an hour this curling prominence faded entirely away.

The planets catch a little of this scattered radiance, but the bulk of it is lost in the outer darkness of space. If the portion of light and heat received by the Earth be represented by the figure 1, the part which misses the Earth will be represented by 2,200,000,000. So that what we get is equal to *one cent* out of *twenty-two*

millions of dollars. What all the planets catch is equal to *ten cents* out of the same amount of money. All the rest escapes into outer space and is apparently wasted.

The amount of "waste" may be conceived from the fact that (in spite of the loss by absorption in passing through the sierra, etc.) every square foot of the Sun's surface continually sends out into space about 10,000 horse-power of radiant energy, while a square foot of our Earth's surface receives about a quarter of one horse-power.[1]

CAUSE OF SOLAR HEAT

Although we cannot see what is taking place beneath the photosphere of the Sun, we can learn something of its anatomy and physiology by indirect methods. All the surface phenomena, revealed by the telescope and spectroscope, are due to deep-seated mechanical and physical processes. Our knowledge of the effects of known mechanical and physical laws enables us to form some idea of what is going on below. The whole body of the Sun appears to be composed of concentric gaseous layers, like the coats of an onion. Each shell is denser than the layer above it, and therefore thinner than the one below. As the outer layers cool off by the radiation of their heat into space, they settle down onto the lower layers and urge them to a quicker rotation. This makes the Sun a huge electrical machine, generating an enormous amount of energy, which manifests itself in different forms. When the various layers have reached a certain density, there is a periodical overheating of the lower layers through the progressive cooling of the upper ones. This periodical overheating causes the layers to react on one another with great violence. The overheated gases escape at every weak place, and these periodical outbursts of energy are visible on the surface in the form of eruptive prominences, Sun-spots, etc. (see Figure 76).

[1] This latter would in one year lift 60 short tons one mile high; the former would lift 40,000 times as much.

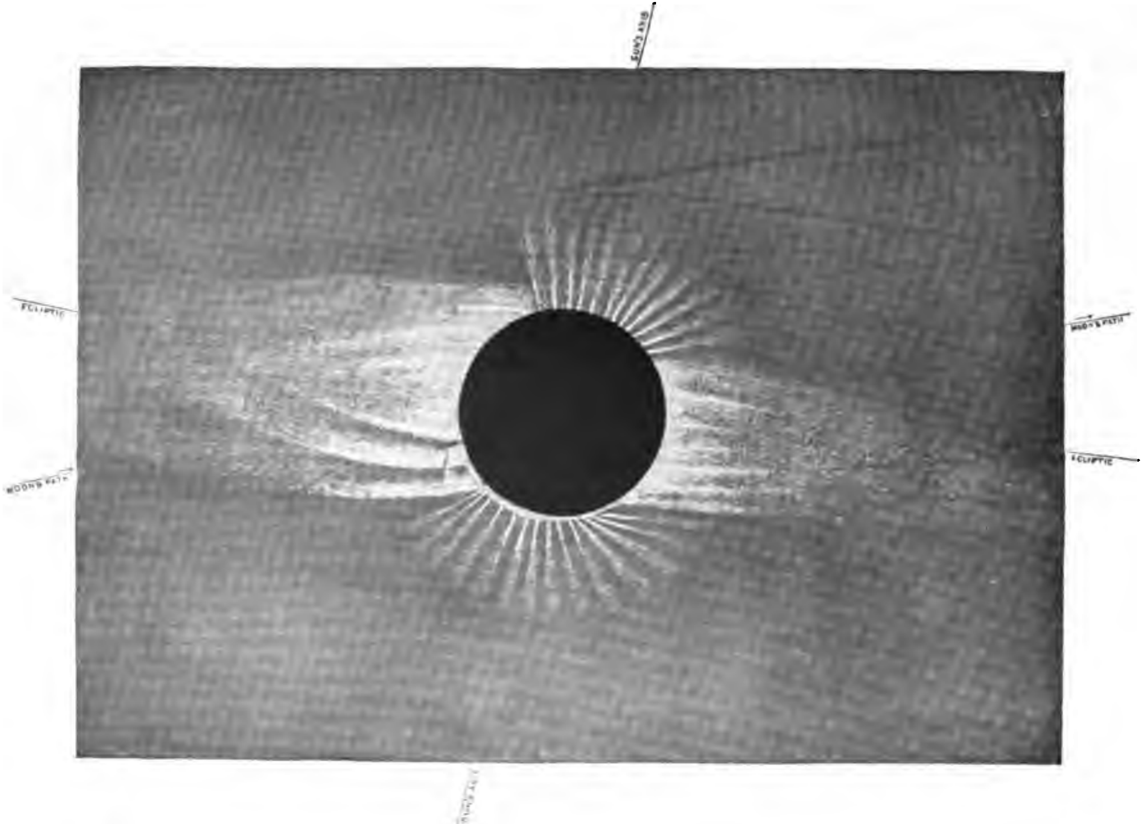


FIG. 75. — THE SOLAR CORONA DURING THE ECLIPSE OF JULY 29, 1878
Drawn by Trouvelot, at Harvard. (*From Comstock's "Text-book of Astronomy," published by Messrs. D. Appleton & Co.*)

So much for the physical constitution of the Sun. If the reader will now turn back to the section entitled "Classes of Stars," in Chapter VIII, he will be able to form some idea as to the physical condition of nebulæ, stars, and planets, at different stages of evolution.

OLD AND DYING SUNS

The common variability of red stars is evidently the outer manifestation of the death-struggles of old and waning suns. The vital forces of the aged stars are no longer able to prevent the various elements from forming chemical combinations, resulting in periodic fluctuations. Their interior forces are making tremendous but unsuccessful efforts to throw off the cooling vapours above, which are gradually choking the life out of the dying suns. Some of them are nearly invisible, except when these paroxysms are at their height. During these periodical spasms, they glare out strangely into the darkness for a time, and then subside. Their struggles grow feebler as time goes on, and finally their uneasy flickering subsides into the calmness and tranquillity of solar death.

CHAPTER XII

A REELING WORLD

"Learned Faustus,
To know the secrets of astronomy,
Graven in the book of Jove's high firmament,
Did mount himself to scale Olympus' top,
Being seated in a chariot burning bright,
Drawn by the strength of yokèd dragons' necks.
. . . . . .
When Faustus had with pleasure ta'en the view
Of rarest things, and royal courts of kings,
He stayed his course and so returned home ;
Where such as bare his absence but with grief,
I mean his friends and near'st companions,
Did gratulate his safety with kind words,
And in their conference of what befel,
Touching his journey through the world and air,
They put forth questions of astrology,
Which Faustus answer'd with such learned skill
As they admir'd and wonder'd at his wit."

—*Marlowe*, "Faustus."

A BIRD'S-EYE VIEW

IN order to ascertain some more particulars about our own Earth, let us go back, for a time, to our Chariot of Imagination, and once more watch our Solar System from a short distance away.

Let us suppose that we are so situated in space that the Sun and planets appear as though they were floating in front of us, on the surface of a sheet of perfectly clear water. And let us suppose that (owing to a slight eddy in the water) the planets are all circling slowly around the Sun. When they are between us and the Sun, they drift to the right, but when they are beyond it they go to the left. The surface of this imaginary sheet of

water will, to an inhabitant of the Third Planet, represent the plane of the Ecliptic, the so-called path of the Sun.

From our supposed position in space, we can not only see our own Solar System spread out before us, but also, in the far distance, the innumerable starry systems which surround it. Those

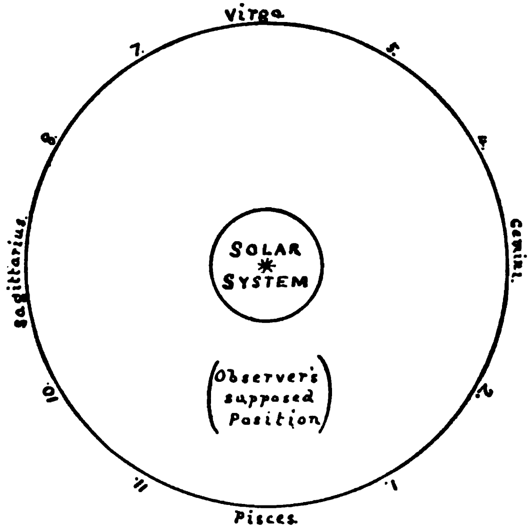


FIG. 77. — DIAGRAM ILLUSTRATING ZODIAC

stars which are on or near the horizon of our imaginary sheet of water may be conveniently divided into twelve equal groups or constellations.[1]

Among these twelve Signs of the Zodiac, or Ecliptic, are those which bear the names of Sagittarius, Virgo, Gemini, and Pisces. As these constellations will hereafter be used to indi-

[1] Named as follows:

1. Aries, the Ram.
2. Taurus, the Bull.
3. *Gemini*, the Twins.
4. Cancer, the Crab.
5. Leo, the Lion.
6. *Virgo*, the Virgin.
7. Libra, the Balance.
8. Scorpio, the Scorpion.
9. *Sagittarius*, the Archer.
10. Capra, the Goat.
11. Aquarius, the Water-Bearer.
12. *Pisces*, the Fishes.

cate planetary motions, their relative positions on the Ecliptic are here indicated (see Figure 77).

Keeping these positions in mind, let us now turn our eyes back to our own Solar System.

If we get out our telescopes and watch the Third Planet, which is now known to us as the Earth, we shall see that its North Pole is uppermost, but that it has *a heavy list to the right.* As the globe spins around, the markings on its near side move to the right, with a slight downward tendency due to the planet's inclination.

One result of the planet not floating quite erect is that the rotation causes its tropical regions to be continually dipping into the water and emerging from it, while the rest of the globe remains all the time either above or below the surface, which represents the plane of the Ecliptic.

On turning to the other planets for comparison, we find that they are rotating in the same direction. Some of them have satellites, or moons, and these appear to drift around their primaries in the same direction, as though the rotation of each planet caused a secondary eddy in the water. It will be seen, therefore, that all these movements — (1) the revolution of the planets around the Sun, (2) their rotation around their axes, and (3) the revolutions of the satellites around their primaries — are in the opposite direction from that taken by the hands of a watch.[1]

A closer view of the satellites would show that their rotation also agrees in direction with the three motions just described. Some of the satellites have adjusted the speed of their rotation to that of their revolution, so that they always show the same side to the world they attend.[2]

It is hardly necessary to say that all these agreements are not

[1] The satellites of the two outside planets do not at present conform to the general rule, though they probably will in the course of time. These planets appear to have been formed later than any of the others.

[2] The two inner planets appear to have done the same thing, so that they always turn the same side to the Sun.

accidental. There is a cause for them, as will be seen in a later chapter.

If we stay where we are, and watch the movements of the Earth for a few years, we shall see that while it drifts around the Sun its axis keeps the same position. The result is that a person living at the North Pole would have the same star overhead all the year round.

When the Earth is to the right of the Sun, it is obvious that the North Pole is in the dark, and that it is winter in the Northern Hemisphere (see Figure 12). When the Earth gets beyond the Sun, both poles are just lighted up by it, and the days and nights are equal all over the globe. This is known in the Northern Hemisphere as the *Spring Equinox.* When it arrives at the left of the Sun, the North is enjoying its *summer,* and the South Pole is in the dark. Finally, when the Earth reaches our side of the Sun, the days and nights are again equal all over the globe. This is known in the North as the *Autumnal Equinox.* As already stated, the axis of the Earth does not share in any of these movements of the planet, but remains fixed with regard to the stars.

Let us now see what ideas the inhabitants of this Third Planet are likely to have with regard to the various movements just described. The rotation of the planet itself they will not be able to perceive, so that, as it spins toward the *east,* they will naturally fall into the delusion that the stars themselves are rolling over toward the *west.* They will also naturally think that the Sun and planets are doing the same thing. But as they are also ignorant of the fact that their Earth is leaning over to one side, they will be surprised and puzzled to find that the Sun gradually drifts toward the north and south as summer and winter approach. They will also find it hard to account for the erratic manner in which the planets appear to move, or for the fact that they always keep on or near the Sun's path.

To an outside observer these circumstances seem to be too simple to require explanation, but to an inhabitant who can neither see, hear, nor feel that his own world is moving, the

whole of the celestial motions are puzzling to the last degree. It speaks well for the intelligence of the inhabitants that many of them have at last managed to find out the real facts of the case.

As the Earth rolls over every day there are two points on the surrounding "star-sphere" which, to an inhabitant of the planet, do not appear to move, but seem to be centres of rotation. These two points are opposite the North and South Poles of rotation. If we let the eye follow the direction of the axis, in an upward (but slanting) direction, till it reaches the stars, it will be found that there happens to be a tolerably bright star near the point around which the other stars appear to move. To an inhabitant of the Earth this star therefore becomes known as the North Pole-Star. Let us keep this in mind, for if the axis of the Earth never changes its position this star will always remain the North Pole-Star so far as the Earth is concerned.[1]

There is another peculiarity about the Earth's motions that is worth mentioning. The World, like all the other planets, does not go around the Sun in an exact circle, but in a nearly circular ellipse or oval. The result of this is that at one part of the year the Earth is about 3,000,000 miles nearer to the Sun than it is six months earlier or later.

From our chosen point of observation the Earth is to the right of the Sun on the 21st day of December in each year, and its North Pole is then turned exactly away from the Sun. This part of the Earth's orbit is termed the *Winter Solstice*, and we will call it the point A. From the Earth, the Sun then appears to be in the sign or constellation of Sagittarius (see Figure 77).

A few days later the Earth reaches that part of its orbit where it is nearest to the Sun. This part of the orbit is termed its *Perihelion*, and we will call it the point B.

[1] In "Julius Cæsar," Shakespeare makes one of his characters say:

> "I am constant as the Northern Star,
> Of whose true-fixed and resting quality
> There is no fellow in the Firmament."

OUR FIRST VISIT (A.D. 1900)

Let us note the relative position of these two points in the year 1900 A.D. (10° apart, measured from the Sun). Then we will wait for a few thousand years, so as to see whether the two phenomena always continue to happen in the same places.

SECOND VISIT (A.D. 8400)

After amusing ourselves by travelling among the stars for 6,500 sidereal years we return to our System (in the year 8400 A.D.), and look for the Third Planet. It is still spinning away like a top that is wound up for ever. But, strange to say, there has been a remarkable change in the position of the two points A and B. The northern end of the polar axis, instead of pointing away from the Sun when the Earth was *to our right* (see Figure 12), has *reeled slowly back* (or *retrograded*) through a quarter circle. Its opposition (A) to the Sun, therefore, takes place when the Earth is *between us and the Sun.* If we regard the Earth as the hand of a watch (going around the Sun once a year, the opposite way to the hands of our watches), it is evident that this watch has gained a quarter of a year (90° of arc, measured from the Sun). For the inhabitants will tell you that it is the 21st day of December, while it is evident that it ought to be the 22d of September so far as the earthly revolutions are concerned.

The result of this is that the Earth has now *another Pole-Star*, and the old one appears (to the creatures on the Earth) to go circling around it like all the other stars. The twelve monthly "mansions of the Sun" have also swung a quarter round, so that they are occupied by different sets of stars. From the Earth, the December Sun now appears to be in the constellation of Virgo instead of being in Sagittarius as before (see Figure 77).

Let us see whether there has been any change in the perihelion (B), the place where the Earth is nearest to the Sun. Yes, it has moved *forward* in the orbit about 20° of arc. The two points A and B, which were only 10° apart, are now 120° apart

(10°+90°+20°=120°). The combined result of the two changes is that, instead of being nearest to the Sun at the beginning of January, the Earth is now in perihelion toward the end of April.

THIRD VISIT (A.D. 14900)

Let us now go away a second time for 6,500 years, and then come back to our Solar System again (in the year 14900 A. D.).

The points A and B have gone on separating at the same rate, so that the angle between them is now 230° of arc (10°+ 110°+110°=230°), measured, as before, from the Sun. It is therefore December 21 when the Earth is *to the left of the Sun*. A *third* and distant Pole-star has replaced the second one. The December Sun is now in the constellation of Gemini, and the Earth is nearest to the Sun in August.

FOURTH VISIT (A.D. 21400)

A third time we retire for the same length of time, and then go back to our old acquaintance (A. D. 21400). By this time the Earth-clock has *gained three quarters of a year with reference to the stars*, or *nearly a year with reference to its perihelion* (10°+110°+110°+110°=340°). The Earth is now *beyond the Sun in December*. A *fourth* Pole-star has replaced the third one. The December Sun is now in the constellation of Pisces, and the Earth is *again* nearest to the Sun in December.

FIFTH VISIT (A.D. 27900)

Once more we go away for the same length of time. On our return (in the year A.D. 27900), the points A and B have passed each other. The Earth-clock has *gained a whole year with reference to the stars*, so that the inhabitants tell us we are a year overdue. December 21 has at last reached its old camping-ground to the right of the Sun (as in Figure 12). The old Pole-star, that we knew so well 26,000 years ago, has returned to its place of duty. And so have the twelve Signs of the Zodiac, so that the December Sun is once more in the constellation of

Sagittarius. But the points A and B are now 90° apart, so that the Earth, instead of being nearest to the Sun at the opening of the year (as at our first visit, in the year A. D. 1900), does not reach its perihelion until March. Figure 78 shows the positions of A and B at the various dates mentioned.

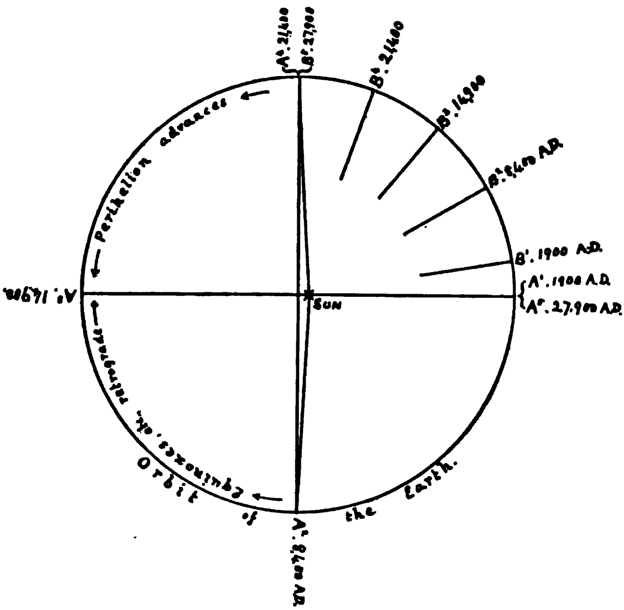


Fig. 78.—Diagram Illustrating Precession of Equinoxes and Advance of Perihelion

The places marked A 1, 2, 3, 4, 5, are the positions of the Earth at the Winter Solstice, at the dates mentioned. The places marked B 1, 2, 3, 4, 5, are the positions where the Earth is nearest to the Sun at the dates mentioned.

We have now followed the backward reeling of the Earth's axis for one complete revolution, which has taken 26,000 years.[1] This reeling of the Earth's poles *around the poles of the Ecliptic* is known as the *Precession of the Equinoxes*, because it makes

[1] More exactly, 25,868 years.

the spring and autumn equinoxes come a little sooner every revolution than they would otherwise do. It is in some respects similar to the slow wabbling motion of a child's top. We may almost say that our World is a big top which spins and wabbles as it swings around the Sun.[1]

EIGHTEENTH VISIT

If we were to keep up our periodical visits to the Earth till the point B, where it is nearest to the Sun, has advanced one complete revolution to its old place, it would take about 13 more visits, 6,500 years apart. For this point, called the Earth's perihelion, takes 109,000 years to complete its circuit.

MILLIONS OF YEARS LATER

Suppose that we now leave our System for — say x millions of years — and then come back to it. What changes shall we find on our return?

In the first place we shall have some trouble in finding our Solar System at all, for in the meantime it has drifted so far that, if its curved path were straightened out, it would be equal in length to $8x$ times the distance of Sirius. And its Sun has changed from a yellowish-white star to a dark-red one, with periodical spasms of brilliancy.

In the second place, when we have found it, picked out the wizened relic of our once-beautiful Earth, and taken our star-photographs, we shall discover that the almost inperceptible drifting of the stars has by this time completely changed the face of the heavens. The "sweet influences" of the Pleiades (Job xxxviii, 31) have now been dissipated and lost. The "Bands of Orion" are loosed for ever. The "Mazzaroth" (or Signs of the Zodiac) are no more waiting to be led forth in their season. And the Great Bear, with her cub, no longer remains to be led around the "pole." Of all the constellations

[1] The cause of the Precession of the Equinoxes will be dealt with in chapter XV.

we used to know so well, not one is now recognisable, though myriads of shining suns still sparkle in the ebon "vault."

On this our last visit to the Solar System we not only find that the Sun has changed its colour and lost much of its former size and brilliancy, but that the planets are not in the same condition they were in before. The Third Planet, for example, rotates very much slower than it used to, and its Moon is farther from it. The result is that the Earth's day and month are now the same length (equal to about 57 of our days). The Moon still shows but one side to the Earth, and the Earth now shows but one side to the Moon. They move around their common centre of gravity like a huge dumb-bell with an invisible handle. The Earth's oceans have partly frozen, and partly soaked into the cold interior. And its atmosphere has congealed into a solid snow-like substance. Like its Moon, it is a dead world, waiting for the inevitable crash that is to bring it back to some other form of life and usefulness.

ORBITS VARY

It may be as well to mention here that the Earth's orbit is not always the shape it is now. Sometimes it is almost circular, while at other periods its ellipticity is so great as to make the Earth's distance from the Sun vary 14,000,000 miles, instead of 3,000,000 miles as at present. This change (combined with the Precession of the Equinoxes, and various geographical changes) produces considerable variations in the Earth's climate at long-distant periods.

If we regard the Solar System as a machine, we shall see that one of its eccentrics takes 109,000 years to go once around. Yet there are people on Planet Number Three who think that the whole Universe, stars and all, was made and wound up 6,000 years ago, and that in another thousand years the entire machine will have run down and worn out!

ORBITS ARE TILTED

Before quitting my illustration of a floating Solar System it may be as well to say that, besides being unreal (a mere detail)

it is faulty, even for an illustration, in one rather important particular. I have imagined the various planets to be floating on the surface of water. Now the fact is that the plane, or level, or surface, on which one planet moves, is not *exactly* the plane or surface on which the others move, so that, if the Earth be regarded as floating evenly on this ecliptic plane, each of the other planets will be found to rise a little above its surface at one part of its orbit, and to sink a little below it at another.

This is the reason why there is not an eclipse of the Sun every new-moon, and an eclipse of the Moon every full-moon. It is only at the two *nodes,* where the plane of the Moon's orbit crosses the plane of the Earth's orbit, that eclipses can occur. For elsewhere the Moon passes below or above the straight line connecting the Earth and Sun. The same is true of the "transits" and "occultations" of the planets in front of, or behind, the disc of the Sun.

SAME POLE-STARS EVERY 26,000 YEARS

Now suppose that the first time we visited the Solar System we took a complete set of photographs of the stars as seen from Planet Number Three. And suppose that on each of our subsequent visits we take a fresh set of photographs. On comparing these we shall find that the stars themselves are about the same, but that what should be called (but are not) their celestial "latitudes and longitudes" are changing all the time. This is of course due to the fact that the North and South Poles are all the time slowly circling around the poles of the Ecliptic.[1] But if we make many visits with the same interval between them, we shall find *every fourth set practically the same.* Thus the *first* and *fifth* sets will be nearly alike, and so will be the *second* and *sixth*, the *third* and *seventh,* and the *fourth* and *eighth.* The reason for this is obvious, for when the poles have "wabbled" around a complete revolution they come back to the same place on the "star-sphere," and the twelve monthly

[1] See North Polar Star Chart.

"mansions of the Sun" again coincide with the same constellations of the Zodiac.

STARS ARE DRIFTING

But if we make a closer examination of our different sets of star-maps we shall find that the stars themselves are slowly moving about in space. One group of stars is drifting in this direction, and another in that. Some are coming nearer to us, and others are receding. Even in a group of drifting stars the individuals are moving slowly around among themselves, like the motes in a sunbeam. This slow drift will eventually make the heavens unrecognisable.

THE GREAT PYRAMID

It is interesting to know that when the Great Pyramid of Egypt was constructed, the North Pole of the Earth was nearly as represented in our third return to the planet. The building was "oriented" (that is, adjusted to the points of the compass) by making a descending passage, down which the pole-star of the period (Alpha Draconis, also known as Thuban) shone at its lowest meridian passage. A temporary pool of water was formed some distance down the passage, and the image of the star reflected up a second (but ascending) passage. The result was that the Pyramid was better oriented than any other building put up before the invention of the telescope. This peculiarity fixes the date at which the Pyramid was built at 3,400 B.C., the December Sun being then in the constellation of Aquarius (Number 11 in Figure 77).

The long, narrow, but lofty gallery which formed a continuation of the ascending passage was the most perfect *transit instrument* ever made, leaving out those provided with magnifying instruments. The large square platform at the top, probably provided with corner-posts and observing-stations, was also an excellent arrangement for the study of the heavenly bodies. By the long-continued use of this truncated pyramid the science

of astronomy might have been largely developed. But unfortunately it was covered up for a tomb as soon as its childish astrological purpose had been served.

THE FIRST POINT OF ARIES

In this chapter I have kept track of the planetary motions by referring to the constellation which the Sun appears to occupy *in December*. In practice it is found more convenient to note what stars are beyond the Sun at the *Spring Equinox*. Four thousand years ago the March Sun was in the constellation of Taurus (the Bull). The Apis worship of Egypt was probably founded on this fact. In Europe it was handed down from father to son by such poetical expressions as "the White Bull opens the year with his golden horns." Two thousand years later, when the same equinox had moved back to the constellation of Aries (the Ram), Jupiter Ammon was represented with a ram's horns. At present the spring equinox is in the constellation of Pisces (the Fishes), and is moving in the direction of Aquarius (the Water-Carrier).

When this slow-moving point was on the margin between Aries and Pisces, it acquired the name of "the First Point of Aries," and it still retains this now misleading name.

It may perhaps prevent a misunderstanding if we regard the Sun (when viewed from the earth) as *advancing* from right to left into a fresh "house" every month, while the solar houses themselves are hooked on to the equinoxes and solstices, and therefore drift *backward* at an extremely slow rate. As the constellations of stars do not share in this backward drift, the effect is as though the celestial bull, ram, fishes, etc., were drifting *forward* from one house to another, entering a fresh "house" every 2,155 years. Or we may imagine that there are twelve picture frames fastened on to the Ecliptic, and that the Sun goes from one frame to another in a month, going from right to left. It will thus occupy one frame every January, the next one, to the left, every February, etc. In this case the stars

form the framed pictures, and they very slowly drift in the same direction, staying in each frame a little more than 2,000 years.

DECLINATION AND RIGHT ASCENSION

In mapping out the heavens it has been found convenient to divide them into 360 "longitudinal" degrees (or into 24 hours), by imaginary lines passing through the Celestial Equator to the poles. The zero of these divisions crosses the Equator and Ecliptic where they cross each other at the so-called First Point of Aries. The same number of "latitudinal" degrees are used to denote the distance of any celestial object north or south of the Celestial Equator. These celestial circles are identical with the terrestrial longitudes and latitudes which are used to denote the position of any place on our Earth. For convenience, the earthly *longitudes* have their zero at Greenwich, England.

For the sake of simplicity, let us suppose, for a time, that we are living at Greenwich. We shall find that, owing to the daily rotation of the Earth, the First Point of Aries appears to cross the local meridian every twenty-three hours and fifty-six minutes. At the moment of crossing, the two longitudinal zeros coincide, and all the stars which are on the local (Greenwich) meridian at that instant *might be* said to have a *longitude* of 0°, or of 0 hours. To prevent confusion, however, they are said to have a *Right Ascension* of 0°, or of 0 hours.

The number of hours and minutes which elapse before a certain star passes the same (Greenwich) meridian is termed the right ascension of that particular star. For example, a star which is on the meridian of Greenwich six hours later than the *Equinoctial Colure* which contains the First Point of Aries is said to have a *right ascension* of 6 hours, or of 90°.

The number of degrees separating a star, etc., from the celestial equator *might be* known as its *latitude*, but for convenience it is really known as its *North* (or *South*) *Declination*. For example, if it is 20° south of the Celestial Equator, it is said to have a *south declination* of 20°.

By measuring the position of a star or other object in these two ways, its position in the heavens can be registered with an accuracy which is limited only by the imperfections of the observers and their instruments.[1]

CELESTIAL LATITUDES AND LONGITUDES

It will be noticed that both of these celestial measurements start from zeros which move around with the Precession of the Equinoxes. The result is that both the declination and right ascension of every star change very slowly as the Earth's axis reels round the poles of the ecliptic. To avoid this objection, it would be necessary to use *latitudes* and *longitudes* based on the ecliptic and its poles. For most purposes, however, the equatorial and polar measurements are most convenient.

IMPROVED EQUATORIAL INSTRUMENT

At the close of the First Chapter I described a very primitive form of equatorial instrument which could be used to "place" the various heavenly bodies, and to follow their motions, both real and apparent (see Figure 6).

This instrument can be greatly improved, so far as right ascension is concerned, by fixing a cog-wheel with 24 teeth at one end of the polar axis, and placing a spring so that it presses against one of the teeth. On turning the telescope or pointer around toward the east, the spring will click off the hours of right ascension. When the pointer is directed to Alpheratz, the upper left-hand star in the Square of Pegasus, or at the most westerly star in the W of Cassiopeia, it is at the zero of right ascension, which passes through the First Point of Aries. One click will bring it to the right ascension of Mirach, in

[1] When the observer does not live at Greenwich, he has to allow, in all his calculations, for the difference in time and latitude. For, on the one hand, it is obvious that if the First Point of Aries is on the meridian of Greenwich, it cannot at the same time be on the meridian of New York or San Francisco. And, on the other hand, it is also obvious that a star that is on the zenith at Greenwich is a long way from the zenith of Cape Town.

Fig. 79. — Equatorial Mounting of the Crossley Reflector, Lick Observatory

With a 36-inch mirror.

Fig. 80. — Meridian Circle

A combination of transit instrument and mural circle.

Andromeda. Another click will bring it in a line with Alpha Arietes, also known as Hamal. Between the fifth and sixth clicks it will pass Rigel and Betelgeuse. At the tenth click Regulus will be in line. Soon after the fourteenth, Arcturus will line up. Between the eighteenth and nineteenth, Vega will be passed; and at the twenty-third click the two right-hand stars of the Square of Pegasus will fall in line. Each click will of course represent one hour (or 15°) of right ascension (see Star Charts and Keys).

The same instrument can also be greatly improved, so far as north and south declination is concerned, by fixing a similar cog-wheel and spring where the telescope or pointer turns on the polar axis. On turning the telescope or pointer to the north or south, the spring will click off every 15 degrees. When it points to Mintaka, the northwestern star in the Belt of Orion, it will be on the equatorial zero. One click to the north will bring it to the declination of Aldebaran, in Taurus, and of the southern stars in the Square of Pegasus. One click to the south of the equator will almost bring Sirius in line. Three to the north will give the equatorial distance of Capella and Arided. Two clicks to the south will bring it to the declination of Fomalhaut (see Star Charts and Keys).

By having three times as many teeth in the two cog-wheels, every click will represent 5 degrees, and the positions of the stars, etc., can be more accurately ascertained. Many modern telescopes have wheels or circles so finely divided that the divisions have to be read off with the help of a microscope. And their polar axis is turned by clockwork, so as to keep up with the (apparent) diurnal motion of the heavens (see Figures 43, 46, and 79).

The right ascension and north and south declination of "many ten thousands" of stars are accurately recorded in star catalogues. By turning the two axes of an equatorial telescope till the index fingers point to the position of a star as given in these catalogues, it is at once placed in the centre of the telescope's field of view. This can be done even in the daytime,

and some of the stars and planets can be found and observed telescopically while the Sun is above the horizon.

MERIDIAN INSTRUMENTS

If the instrument described above is pointed to the zenith (or point overhead), and the polar axis is then permanently clamped, the range of the telescope is reduced to a straight north-and-south line, forming one half of a great circle of the heavens. It can be pointed to the northern horizon, to the polar axis of the heavens, to the point overhead, to the southern horizon, or to any intermediate point. But it cannot be directed to any part of the heavens either east or west of the local meridian. In order to observe any heavenly body with this crippled equatorial it is necessary to wait until the apparent diurnal motion of the heavens brings the object to the meridian. Supposing that we are still at Greenwich, let us wait till the zero of right ascension passes the field of view, and then turn the hands of a 24-hour clock till they point to 24 o'clock. The clock will then register what is known as *sidereal time*.[1]

As the northeast star in the Square of Pegasus is at present close to that zero, we can start the sidereal clock when that star crosses the field of view. It will be found that the star known as Mirach passes at one o'clock (sidereal), Alpha Arietes at two, Regulus at ten, and Arcturus at fourteen o'clock. These stars are therefore said to have so many hours of right ascension, and by measuring the number of degrees they are north or south of the Equator (90° from each of the Poles) we can ascertain their north or south declination.

These two classes of observation are so important that greater precision is obtained by using a special instrument, with no polar axis, but with large and carefully constructed declination circles. This instrument is called a Meridian Circle (see Figure 80). It is mounted on a horizontal axis lying east and west. This axis rests on the top of two massive piers, so that

[1] It should be regulated so as to gain four minutes in 24 hours of solar time.

the arrangement is similar to that of a cannon mounted on its carriage.

When this meridian circle is being used as a *transit instrument*, the exact sidereal time when a celestial body crosses the centre of the field of view is observed, and the star or planet is said to have a right ascension of that number of hours, minutes, and seconds.

When this meridian circle is used as a *mural circle*, to find the distances of stars, etc., from the Celestial Poles or Equator, the clock is disregarded, but their distances from the local zenith are carefully read off on the large declination circles attached to the axis of the telescope. As the distances of the local zenith from the Celestial Pole and Equator have been previously ascertained, the zenith distance of any object can easily be turned into either "polar distance" or declination (north or south), as may be preferred.

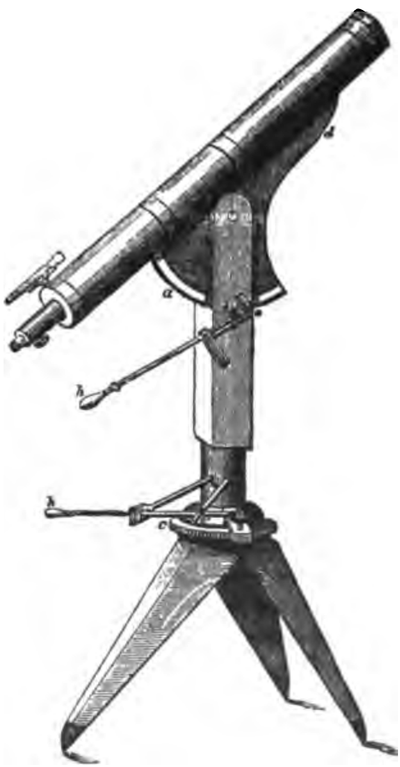


FIG. 81. — ALT-AZIMUTH MOUNTING FOR SMALL TELESCOPE

One of the screw motions changes the altitude, and the other, the azimuth or point of the compass.

ALT-AZIMUTH TELESCOPE

There is another form of telescope-mounting known as the *alt-azimuth*. As its name implies, this gives two motions, one around a perpendicular axis, changing the "azimuth"

or point of the compass, and the other around a horizontal axis, changing the "altitude" (see Figure 81). This form of mounting, though very handy for terrestrial purposes, is inconvenient for celestial objects, which almost always move at an angle with the horizon. For any one living at the North or South Pole, however, it is the best form, as the perpendicular axis becomes a polar axis, and the instrument is transformed into an equatorial.

USES OF INSTRUMENTS

It will be seen from the above that both the alt-azimuth and the equatorial are capable of being directed to any part of the sky, and can be made to keep a celestial object in view for any length of time, provided that it is above the horizon. The alt-azimuth is, however, difficult to use for most astronomical purposes, as the diurnal motions can be followed only by turning both axes at the same time. The equatorial form is therefore commonly used for general observational purposes. The various attachments used for celestial photography and spectroscopy are all applied to telescopes so mounted, with a clockwork movement to the polar axis, to neutralise the apparent motions due to the Earth's rotation.

The meridian circle, however, moves solely on the local meridian, and no celestial object can be seen through its telescope except for a few seconds every 24 hours, as it crosses the field of view from east to west. Of course such a telescope is of no use for "star-gazing." Its chief purpose is for measuring the polar distances and hour angles of the heavenly bodies on the celestial "sphere."

CHAPTER XIII

KEPLER'S THREE LAWS

"In the phenomena presented to him, man must [have early noticed] two kinds of relation. Some things show themselves *with* other things, and some things *follow* other things. These two kinds of relation we call relations of *co-existence*, and relations of *succession* or *sequence*. Since what continues is not so apt to attract our attention as what changes, it is probable that the first of these two relations to be noticed is that of succession. . . . Now of the sequences which we notice in external nature, some are variable, . . . while some are invariable. . . . As to these *invariable sequences*, which we properly call *con-sequences*, we give a name to the causal connection, between what we apprehend as *effect* and what we assume as *cause*, by calling it a Law of Nature. . . . In original meaning the word *law* refers to *human will*, and is the name given to a command or rule of conduct imposed by a superior upon an inferior, as by a sovereign or State upon those subject to it. At first the word *law* doubtless referred only to *human law*. But when, later in intellectual development, men came to note invariable co-existences and sequences in the relations of external things, they were, of the mental necessity already spoken of, compelled to assume as cause a will superior to human will, and, adopting the word they were wont to use for the highest expression of human will, called them *laws of Nature*. Whatever we observe as an invariable relation of things, of which in the last analysis we can only affirm that 'it is always so,' we call a law of Nature." — *Henry George.*

UNCHANGING LAWS

PERHAPS the most striking thing in the study of astronomy is the fact that everywhere there are evidences that the whole Universe is absolutely ruled by unchanging laws. There is no such thing as chance. Hesitation and uncertainty are unknown. Knowing the forces which are at work, the astronomer can calculate with certainty the positions and movements of the other planets in our System for thousands of years to come. And even beyond our System, at distances which are too vast for the imagination itself to fathom, he can

follow up the movements of some of the stellar groups and predict their future positions and relations.

In order to do these things he has to cast aside all ideas of chance or miracle, and rely entirely on the immutability of the laws of Nature.

These natural laws must not be confounded with mere human decrees, which are all more or less arbitrary, changeable, and local, as well as ineffective. Human laws may to-day decree that in a certain country one kind of stealing shall be legal and praiseworthy, while another kind of stealing shall be criminal and punishable; and to-morrow the decree may be reversed, if the rulers think fit. For example, in Old Testament times it was against the law to charge interest (usury). At present it is a legal and even respectable custom. Some day it may again become a crime.

But natural laws exist without any decree being promulgated. *They are not the creation or invention of mind,* but the inevitable result of mathematical necessity. They rule alike the entire Universe. All matter is absolutely subject to them, whether it be dead or living. They are the same to-day as they were a billion or a trillion years ago, and they will be the same a billion or a trillion years to come. For example, $2 + 2 = 4$, always and everywhere. Omnipotence itself could not invent or change this natural law. It would be just as true if nothing existed.

George N. Lowe says of Natural Law —

> "The Law no contract knows, no lease
> Of being, waning past its prime —
> She moves but in Eternities;
> Supreme, she hath no need of Time."

Dr. J. W. Draper, in his "Conflict Between Religion and Science," says:

"Astronomical predictions of all kinds depend on the admission of this fact — that *there never has been, and never will be, any intervention in the operation of natural laws.* The scientific philosopher

affirms that the condition of the [Universe] at any given moment is the direct result of its condition in the preceding moment, and the direct cause of its condition in the subsequent moment. Law and chance are only different names for mechanical necessity."

KEPLER'S LAWS

It was Kepler[1] who first discovered the music which regulates the whirling of the worlds through space. His explanations of the planetary motions are known as *Kepler's Three Laws*. They are as follows:

I. The orbit of every planet is an ellipse, with the Sun in one of its foci.

II. An imaginary line drawn from the Sun to a planet will sweep over equal areas in equal times.

III. The squares of the numbers representing the periodic times of the planets vary as the cubes of the numbers representing their mean or average distances.

These laws are easily stated, and, to one who understands the meaning of the terms employed, are not difficult to comprehend. To us, indeed, they seem as obvious, natural, and inevitable as the statement that two and two make four.

Yet it was not always so. For thousands of years intelligent astronomers, of many nationalities, were seeking diligently for these three laws, but never found them. After every other theory, probable and improbable, had failed to explain the apparent motions of the planets, Kepler found that the movements of Mars could all be accounted for on the theory that each planet moves in an elliptical orbit around the Sun with a velocity varying with its distance from that body. Let us examine his conclusions.

FIRST LAW

"The orbit of every planet is an ellipse, with the Sun in one of the foci."

In order to comprehend this we must clearly understand what an ellipse really is.

[1] Born in 1571; died in 1630.

Get a piece of white pasteboard. Stick a pin upright on one side of it, near the centre. Tie the two ends of a piece of thread together, so as to make a loop three inches long. Pass one end of this loop over the pin, and insert the point of a pencil through the other end of it. Let the pencil-point touch the card, and move it around the centre-pin so as to make a six-inch circle. This circle is really *an ellipse with no eccentricity.*

Now stick two more pins in the pasteboard, one on each side of the first, so that each is the eighth of an inch from the centre one. Pass the loop over them all, insert the point of a pencil as before, and again move it around on the card, keeping the string stretched all the time. The resulting figure looks like a circle, but it will be found, on measuring it, that it is a trifle narrower one way than another. And instead of having *one centre,* or *focus,* it has *two eccentric foci,* each one being an eighth of an inch away from the centre of the figure. The apparent circle is really *an ellipse of small eccentricity.*

By increasing the interval between the two pins, or foci, we can produce a great variety of ellipses. When the two foci are two inches apart, the resulting figure, instead of being a six-inch circle, is an ellipse measuring 4 inches one way, and 3½ inches the other way. As each focus is some distance from the centre, the figure is termed *an ellipse of great eccentricity* (see Figure 82).

We are now in a position to understand Kepler's First Law, that each planet moves in an ellipse, with the Sun in one of the foci.[1]

SECOND LAW

"An imaginary line drawn from the Sun to a planet will sweep over equal areas in equal times."

The simplest form in which we can study this law is where the elliptical orbit has no eccentricity; that is to say, when

[1] In most astronomical calculations, one focus alone is of importance, the other one being placed on the shelf, along with the so-called "fourth dimension of space."

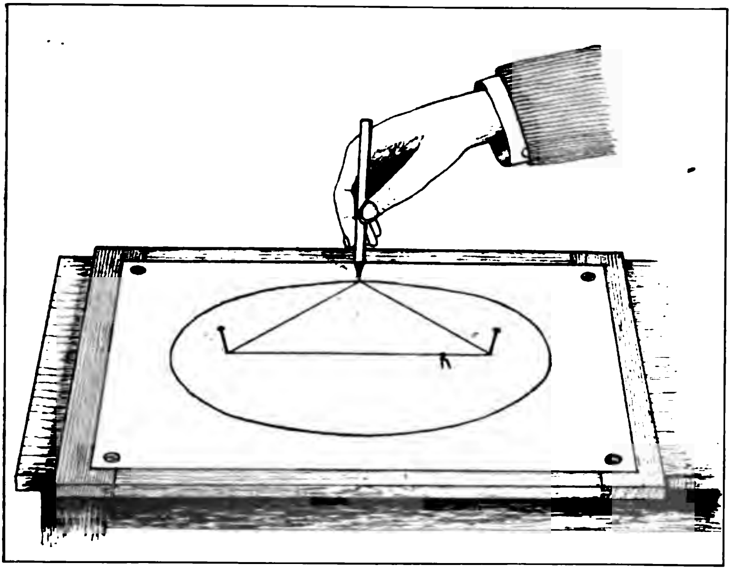


FIG. 82. — DRAWING AN ELLIPSE

the ellipse is a true circle, with the two foci together at the centre.

An ordinary carriage-wheel with twelve spokes will do to illustrate this form of ellipse. The spokes of such a wheel are all of the same length and are the same distance apart.

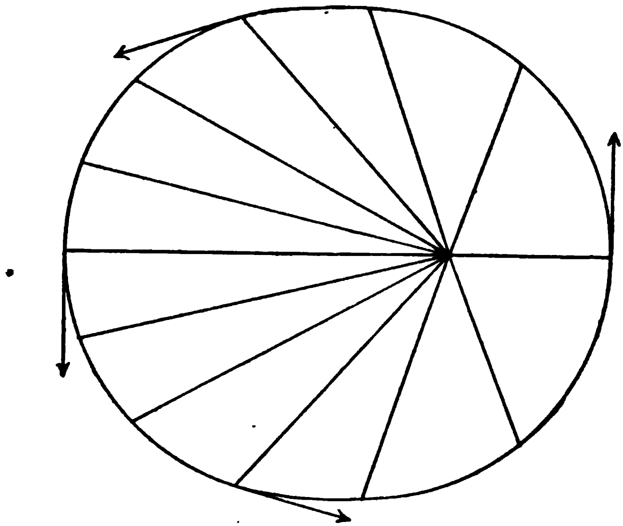


FIG. 83.—AN ELLIPTICAL ORBIT, DIVIDED INTO TWELVE MONTHLY PARTS

This ellipse is more eccentric than the majority of planetary orbits, but is less so than the orbits of comets.

The spaces between them are therefore all the same size; that is, they all contain the same number of square inches.

If an insect should crawl straight along the tire of this wheel at a uniform speed, it is obvious that it would always take the same interval of time to go from one spoke to another, and an imaginary line between the insect and the centre of the wheel would always sweep over the same number of square inches per second.

It is the same in the case of a planet. "An imaginary line drawn from the Sun to a planet will sweep over equal areas in

equal times." So when this line has swept over *one twelfth of the area* of the orbit, *one twelfth-part of the planet's revolutionary period* has passed away.

When the wheel is not a circular ellipse, but an eccentric one, the details are rather different, though the law is the same. In this case the spokes radiate from one of the foci instead of from the centre (see Figure 83). And if the area (or number of square inches) between each of the spokes is to remain the same, it follows that the long spokes must be set closer together than the short ones.

From this it is evident that if the insect wishes to go from one spoke to another in the same interval of time, it must crawl slowly when on that part of the tire where the spokes are long and close together, and increase its speed as it goes to where the spokes are short and far apart.

It is the same in the case of a planet. The speed increases and diminishes according to the planet's distance from the Sun, so that, in this case too, "an imaginary line drawn from the Sun to a planet will sweep over equal areas in equal times." And, as in the case of a circular orbit, when this line (called a *radius vector*) has swept over *one twelfth of the area* of the orbit, *one twelfth*-part of the planet's revolutionary period has passed away.

Figure 83 is an exaggerated view of the Earth's orbit, with 12 "spokes" (or radius vectors) radiating from the Sun, which occupies one of the foci. The Earth goes from one "spoke" to another in an average month (about 30½ days), and therefore travels faster when nearest to the Sun (in *perihelion*) than it does six months later, when it is at its greatest distance from the Sun (in *aphelion*).[1]

[1] If any orbit is correctly marked out in pasteboard, and the twelve wedge-shaped pieces are then cut out, they will all be found to weigh alike, because, though different in shape, they all have the same size or area.

THIRD LAW

"The squares of the numbers representing the periodic times of the planets vary as the cubes of the numbers representing their mean or average distances."

The law which we have just discussed deals with the varying velocity of one planet alone. The one we have now come to compares together the periodic times of different planets, and shows that they have a definite relation to the distances of the planets from the Sun. It also enables us to compare the mean or average velocity of one planet with the mean or average velocity of any other planet. The periodic time of a planet is of course the time it takes to go once around the Sun. In other words, it is the length of the planet's *year*.

The outer planets have a longer journey to make than the inner ones. And they move with less rapidity. Consequently their years or periodic times are considerably longer.

Observation has shown that Jupiter, which is 5.2 times as far from the Sun as our Earth, takes 11.86 times as long to complete a revolution. In other words, Jupiter's journey is a little over 5 times as long as ours, but his year is nearly 12 times as long.

Let us see how Kepler's Third Law fits in with this. If we *square the periodic times*, 1 and 11.86, we get (omitting fractions) the numbers 1 and 140. And if we *cube the distances*, 1 and 5.2, we get 1 and 140. *These results are identical.*

In the above example the smaller period and distance are both represented by unity (1) to save figuring. Here is another example, given in miles and days. The *distances* of Mercury and Venus from the Sun are 46,000,000 and 67,000,000 miles respectively. When these numbers are cubed, the latter exceeds the former $6\frac{1}{2}$ times. Their *periods* of revolution are 88 and 225 days, respectively. When these numbers are *squared*, the latter exceeds the former $6\frac{1}{2}$ times. These results (like those in the Earth-Jupiter example) are identical, and if we perform the operation with any two planets we get a similar

result. So we find that "the squares of the periodic times are in the same proportion as the cubes of the distances."

The velocity of a planet is easily computed when we know the size of its orbit and the length of its year. Jupiter has 5.2 times as far to go as the Earth, so that if he moved with the same velocity he would complete a revolution in 5.2 of our years. As his year is 2.28 times as long as that, the average velocity of the Earth in its orbit is evidently 2.28 times that of Jupiter. Accordingly we find that while Jupiter travels 486 miles per minute, our Earth travels 1,108 miles in the same interval of time ($486 \times 2.28 = 1108$).[1]

Kepler not only discovered that the planets move in elliptical orbits (according to the laws which he formulated), but also convinced himself that their notions were due to mutual attraction between them and the Sun. Unfortunately he was not able to demonstrate this. It was, with him, a probable but unproved theory.

[1] It was afterward discovered by Newton that Kepler's Third Law is the result of the solar attraction alone, so that it is only strictly correct in the case of planets consisting of single infinitesimal particles. Where the planet is large, its attraction must be allowed for as well. The correction does not make much difference in the result, so far as the above examples are concerned, but it enables us to extend the law to the satellites of planets and to stellar systems. The details of this correction will be found in most modern text-books.

CHAPTER XIV

GALILEO'S LAWS OF MOTION

"When we find in Nature certain invariable sequences, whose cause of being transcends the power of the will testified to by our own consciousness; such, for instance, as that stones and apples always fall toward the Earth; that the square of a hypothenuse is always equal to the sum of the squares of its base and perpendicular; . . . and, so on through the list of invariable sequences that these will suggest, we say — for it is really all that we can say — that these sequences are invariable because they belong to the order or system of Nature; or, in short, that they are Laws of Nature. . . .

Why is it that some things always co-exist with other things? The Mohammedan will answer: 'It is the will of God.' The man of our western civilisation will answer: 'It is a law of Nature.' The phrase is different, but the answer one." — *Henry George.*

ARISTOTLE'S THEORY OF MOTION

FROM very ancient times men have tried to find the laws which regulate motion, both on Earth and in the heavens. Aristotle, the founder of science, gave the following as his view of the subject:

"All simple motion must be rectilinear or circular, either to a centre or from a centre, each of which is rectilinear, or about a centre. It is natural for two of the elements — earth and water — to tend *to a centre;* two — air and fire — which are light, to tend *from a centre.* As the motion of all terrestrial elements is therefore rectilinear, it seems reasonable that the celestial bodies, which are of a different nature, should have the only other simple motion possible, namely, circular motion."

This reasoning sounds strange to-day, though it held its own until the time of Kepler. That philosopher finally threw aside the celestial part of it, and substituted his laws of planetary motion, dealt with in the preceding chapter.

GALILEO'S LAWS

The terrestrial part of Aristotle's law also had to give way about the same time. Galileo[1] discovered that on our Earth all bodies move, or abstain from moving, according to the following laws, which were put in their present shape by Sir Isaac Newton.

I. Every body continues in its state of rest, or of uniform motion in a straight line, unless it is compelled to change that state by forces impressed thereon.

II. The alteration of motion is ever proportional to the motive force impressed, and is made in the direction of the straight line in which that force is impressed.

III. To every action there is always opposed an equal reaction, or the mutual actions of two bodies are always equal and directed to contrary parts.

FIRST AND SECOND LAWS OF MOTION

One result of the first law of motion is that a body which is at rest will stay where it is until it is acted upon by some force. This is obvious enough, but there is another result which does not seem so clear. It is that if a body be once set in motion with a certain velocity it will (if not acted on by any other force) continue to move for ever in a straight line and at the same velocity. This tendency to resist change (either of rest or motion) is known as *inertia.*

We have no means of testing this first law by itself, for when we examine an object which appears to be at rest we find that the attraction of the Earth is holding it in its place; and when we set anything in motion we are unable to prevent other forces from acting on it. If we fire a bullet out of a gun, it is acted on not only by the *initial* impulse of the exploding powder *behind* it, but also by the *continuous* attraction of the Earth *beneath* it. It has also to contend with the continuous *resistance* of the air *in front* of it. If any wind is blowing, it may

[1] Born in 1564; died in 1642.

be affected by a *lateral* force as well. All of these modify and finally overcome what (according to this law) would otherwise have been a uniform motion in a straight line.

But, according to the second law of motion, any secondary force impressed on the flying object *produces a change of motion proportional to its own strength.* So that, if we can ascertain how much this second force has drawn the bullet from its path, we can find where it would have gone if the second force had not acted on it.

It has been found by experiment that if a bullet (or any other object heavy enough practically to neutralise the resistance of the atmosphere) is dropped from a height, the attraction of the Earth will cause it to fall 16 feet in a second of time. And we have seen that this force acts on the bullet even when in motion.

Let us, then, select a *perfectly level* piece of ground (which does not share in the convexity of the Earth's surface), and fire a gun *horizontally* at a height of 16 feet above the ground. We shall find that the bullet (instead of keeping on in a straight line parallel with the ground) will bend down *so as to strike the ground in exactly one second of time.* If the act of firing the gun is made to release another bullet at the same instant and from the same elevation, both bullets will reach the ground at the same instant, one of them some distance away, and the other beneath the gun. So far as regards the *time* in which the first-mentioned bullet reaches the ground, it will make no difference whether the charge of powder used is large or small, though of course a large charge will make the bullet strike farther away than it would with a small charge.

Now if we could have prevented the attraction of the Earth from pulling the flying bullet 16 feet out of its course, it would have kept in a straight line at the same distance from the ground.

Thus we see that although the first law of motion cannot be experimentally proved by itself, it can readily be tested in conjunction with the second law. The only difficulty in the ex-

periment is to make a correct allowance for the atmospheric friction. To get the most accurate results, the experiment should be performed in a vacuum, but this is easier said than done.

THIRD LAW OF MOTION

The Third Law, concerning reaction, is true of both attraction and repulsion. It is not only true that a magnet will draw a piece of iron to it, but it is also true that a piece of iron will draw a magnet to it. When a gun is fired, the backward kick of the gun is equal to the forward impulse of the bullet, and if the gun and bullet were of the same weight they would both go the same distance, but in opposite directions.

If two bullets are connected by a string, and then swung into the air, they will circle around each other as they fly. If both are of the same weight, they will swing around the centre of the string. If one is heavier than the other, then the lighter one will make the larger circles. In the latter case the influence of the small bullet will be exerted on a greater mass, and will consequently draw it less out of its course. But nevertheless it is obvious that, as in the case of the bullet fired from a gun, the action and reaction will be equal.[1]

It is rather singular that Galileo, while discovering and fighting for his laws of motion, entirely ignored Kepler's discovery of the three laws of planetary motion, dealt with in the preceding chapter. This has been charitably attributed, not to vulgar jealousy, but to "a certain unconscious intellectual egotism, not always unknown to the greatest minds." — *Ency. Brit.* art. "Galileo."

[1] If anyone still finds these laws of motion hard to understand, he may find his difficulties melt away as he reads them in the simple form in which they were first given to an admiring world. They were published as follows:

I. Corpus omne perseverare in statu quo quiescendi vel movendi uniformiter in directum, nisi quatenus illud a viribus impressis cogitur statum suum mutare.

II. Mutationem motus proportionalem esse vi motrici impressæ, et fiere secundum lineam rectam qua vis illa imprimitur.

III. Actioni contrariam semper et æqualem esse reactionem; sive corporum duorum actiones in se mutuo semper esse æquales et in partes contrarias dirigi.

CHAPTER XV

NEWTON'S LAW OF GRAVITATION

"The force of gravitation acts on every particle of matter, and hence it is not confined to our own World. By its action the heavenly bodies are bound to one another, and thus kept in their orbits. It may help us to conceive how the Earth is supported, if we imagine the Sun letting down a huge cable, and every star in the heavens a tiny thread, to hold our globe in its place. . . . So we are bound to them, and they to us. Thus the worlds throughout space are linked together by these cords of mutual attraction, which, interweaving in every direction, make the Universe a unit." —*J. Dorman Steele.*

THE LAW AND ITS PROOF

THE three laws of motion discussed in the preceding chapter were at first confined to sublunary dynamics. But Sir Isaac Newton[1] showed that the heavenly bodies also are subject to them. He theorised, and after many years of labour proved, that while they were the *cause* of the peculiarities described in Kepler's Laws, they were themselves the *result* of a general principle known as the *Law of Gravitation.*

According to this universal law —

"All bodies in the material Universe gravitate toward each other with a force which is *directly* proportional to their masses, and *inversely* proportional to the *squares* of their distances from one another."

Perhaps the simplest form in which this law can be correctly stated is that "every particle of matter in the Universe pulls every other particle toward it with a force which *decreases* as the *square* of the distance *increases.*"

When the law of gravitation was first brought forward in a theoretical manner, it seemed to be very feasible, but, at the same time, to be incapable of proof. The assumption that the

[1] Born in 1642; died in 1727.

attracting force varies directly in proportion to the masses hardly required any proof; it simply meant that a body composed of three atoms would attract three times as strongly as a body composed of one atom. It could no more be questioned than the statement that three equal masses of iron will, under similar conditions, weigh three times as much as one such mass alone. But the assumption that the attraction of one body for another varies in the inverse proportion to the *square* of the distance separating them was neither obvious nor easily proved. There was this to be said in favour of the proposition, however, that light, heat, and similar forces vary in intensity according to this rule. For example, if a small lamp shines through a square twelve-inch hole in a screen *one yard* away, so as to light up part of another screen *two yards* from the lamp, it will be found that the area illuminated on the second screen contains four square feet. It is therefore four times as large as the hole in the first one, and the intensity of the light is obviously reduced to *one quarter* of what it was at *half* the distance. If the second screen be moved to a distance of *three yards* from the lamp, it will be found that the area illuminated measures nine square feet. It is therefore nine times as large as the hole in the first screen, and the intensity is evidently only *one ninth* of what it was at *one third* the distance. The rule holds good for any distance, provided that none of the light is absorbed by fog, etc.

Newton theorised that the attraction of all the atoms composing the Earth would act as though the pull came from the centre of the Earth. Now this attraction is strong enough to cause a body on the surface (about 4,000 miles from the centre of attraction) to fall 16 feet in one second of time. If this law of gravitation is true, then an object *twice* as far from the centre of the Earth should drop only *one quarter* as far in the same interval of time, an object *three* times as far from the centre should fall only *one ninth* as far in a second, and so on for all distances.

Newton could easily have proved or disproved this theory if

Fig. 84. — Mount Lowe Observatory, in Southern California

he could have gone up 4,000 and 8,000 miles to see how far the Earth's attraction would cause a body at those distances to fall in a second. But unfortunately he was not able to do this.

Finally he found a way to get over the difficulty by taking advantage of the presumed fact that our Moon is kept in her orbit by the attraction of the Earth. It has been already shown that on the Earth's surface a bullet fired horizontally from a gun is, in one second, pulled 16 feet out of its direct course by the attraction of the Earth beneath. That is to say, it falls just as fast when it is flying through the air as when it is simply dropped from the hand. Now the Moon is 60 times as far from the centre of the Earth as we are. Let us look on it as a big bullet fired horizontally at that height. We shall then see that the Earth's attraction is pulling it out of the straight course it would follow if suddenly left to itself. The theory is that the Earth's attraction *decreases* as the *square* of the distance *increases*. The square of 60 is 3,600, so that the Moon should, in one second of time, be pulled out of its straight course the 3,600th part of 16 feet. This is about *one twentieth part of an inch*, and it fits in exactly with the observed motion of the Moon in its orbit. The theory is therefore true, so far as the Earth and Moon are concerned.[1]

The law has since been applied to all the planets revolving around our Sun. The satellites of Jupiter, etc., are found to

[1] Although this law of gravitation was unknown before Newton, its existence and universality were suspected by Galileo and hinted at in his "*Dialogo dei Massimi Sistemi.*" In one place he says:

"Le parti della Terra hanno tal propensione al centro di essa, che quando ella cangiasse luogo, le dette parti, benchè lontane dal globo nel tempo delle mutationi di esso, lo seguirebbero per tutto; esempio di ciò sia il seguito perpetuo delle Medicee, ancorchè separate continuamente da Giove. L'istesso si deve dire della Luna, obligata a seguir la Terra."

Rather freely translated, this reads:

"The different parts of the Earth have such a propensity toward its centre that, though it should change its place, the said parts, although far from the globe in the time of its change, would follow it everywhere. An example of this is the perpetual following of the satellites of Jupiter, although always separate from the planet. There is a similar instance in the case of the Moon, obliged to follow the Earth."

conform to it, and the cometary messengers of heaven are bound by it. Even the starry systems appear to circle in complete bondage to this universal law of gravitation.

PLANETS SECURELY TETHERED

We now come to two questions which often puzzle those who have not made a study of the subject. Why does not a planet, when it reaches its perihelion, continue to approach the Sun in a closing spiral till it finally falls into it? And why does it not, when at its aphelion, continue to recede in an opening spiral, and finally go off into the outer darkness of space? So far as the principles involved are concerned, these questions are not difficult to answer satisfactorily. But mathematics are necessary if we wish to go into details and prove every point.

Let us take a single planet moving in a very eccentric orbit. We will suppose that it has passed its aphelion and is approaching that part of its orbit where it will be nearest to the Sun. As its distance decreases, the increasing attraction of the Sun (being *in the same general direction* as that in which the planet is moving) gradually increases its speed, and therefore *straightens its path.* For, the deflection Sunward being so many inches per minute, if the planet moves faster its course will be straighter.[1] The result is that the planet sweeps by the Sun with a rush that the increased attraction cannot check.[2]

As the planet's distance from the Sun increases, the decreasing attraction (being *almost opposite to the direction* in which the planet is moving) gradually checks its speed. It therefore bends in toward the Sun and finally begins to approach again.

Where the planet moves in an orbit of small eccentricity, the

[1] This is seen on our Earth, where a large charge of powder will send a bullet swifter and therefore straighter than a small charge. If we could stand on the summit of a lofty mountain, and fire a cannon *horizontally* with just sufficient charge, the projectile would sweep around the Earth, and (possibly) knock in the breech-plug of the cannon from behind.

[2] A similar thing takes place with the pendulum of a clock. The Earth's attraction brings it down on one side with a rush that carries it up on the other side.

above phenomena are not so marked, but the principle is the same. In the absence of a resisting medium there is not the slightest possibility of a planet getting into a closing spiral. And an opening one is only possible where tidal influences are very strong. So we need not be afraid of either falling into the Sun or of breaking loose and drifting into the outer darkness. These are only possibilities of the remote future, long after the human race shall have passed away from other causes.

Where a number of planets are revolving around the same sun, at different distances, their mutual attractions slightly interfere with their orbits, producing certain periodical *perturbations*. It was the study of some of these irregularities which led to the discovery of the planet Neptune, 1,000,000,000 miles beyond Uranus, which had previously been regarded as the outside planet of our system.

WHAT IS GRAVITATION?

It appears certain that all matter is under the absolute control of the attraction of gravitation. Atoms and suns are alike ruled by this law. Every motion is regulated by it, every non-motion is the result of it.

Although gravitation is now thoroughly understood, both as to its *mode* of action and the *measure* of its power, there is yet some uncertainty as to its nature. It is generally regarded as a universal property *inherent in matter itself*, but some think that it may be an independent energy controlling matter from the outside.

The original idea was that gravitation reaches out from one particle to another, even when they are separated by great distances, with nothing to connect them, — in fact that there is action at a distance without a medium. This idea has had to be abandoned, for it is evident that a thing cannot act where it is not present. So a connecting *ether* has been "invented" to carry the energy of gravitation (and what is known as radiant energy) across from one particle of matter to another. Whether

this ether really exists, what it is like, and how it acts, are questions that still keep scientists busy, and will probably not be settled for some time to come.

EFFECTS OF GRAVITATION

Whatever it is, the action of gravitation is always mutual, and appears to be instantaneous. It operates at all distances and through all substances.

Its tendency, suddenly applied to scattered bodies previously at rest, would be to bring together all the suns and worlds of which the Universe is composed. But, if applied to bodies already in motion, its effect would be to change direct motions into curved orbits like those of the planets.

Its effect on any isolated body (like the Sun, or our Earth) is to cause its particles to arrange themselves in the form of a sphere, more or less flattened when there is any considerable rotation. In this sphere the densest forms of matter naturally gravitate toward the centre, and, while the globe possesses any considerable amount of internal heat, there may be an outer layer of liquid, with expansive gases outside of all.

On the surface of such isolated bodies its effects are almost inappreciable, the only noticeable effect being that every particle of matter clings to the planet with an intensity varying *directly* with the *mass* of the planet, and *inversely* with the *square* of the *distance* between the body and the *centre* of the planet. On the same globe all things on the surface are at practically the same distance from the centre. Therefore they are all, whether heavy or light, attracted with the same intensity, and (in a vacuum) fall with the same velocity. The *weight* of an object equals its mass multiplied by the force of gravity. If it were removed to a planet where the force of gravity was twice as great, its weight would be doubled, though its mass would remain the same.

Fig. 85. — Spiral Nebula in Ursa Major (M 81)

Lick photograph.

INTENSITY OF GRAVITATION

As regards the strength of the attraction of gravitation, it is really very small, being more than a million times weaker than that of magnetism. Two masses, each of 465,000 American tons, attract each other with a force of *one pound* when they are *a mile apart.* If the distance between them be *doubled,* the attraction is reduced to *four ounces.* If the distance be reduced to *half a mile,* it is increased to *four pounds.* If one of the masses be doubled in size and weight the attractive force is doubled, while if both masses be doubled, the attraction is quadrupled.

OMNIPOTENCE OF GRAVITATION

The above example, taken by itself, might lead one to suppose that the attraction of gravitation is of very slight importance in a Universe where the distances separating the suns and worlds are so vast. But other forces are local, or operate only under certain conditions, while gravitation appears to be universal and to act under all conditions. It therefore becomes *an all-controlling force* whose immensity the mind of man cannot realise. It possesses some of the attributes of Deity, being omnipotent, omnipresent, and eternal. It controls the infinitely great and the infinitely small. It regulates the movements of every speck of dust that dances in a sunbeam, and, at the same time, of every sun that sweeps through the boundless depths of space.

The following illustration will give some faint idea of the immense power of the attraction of gravitation:

In going around the Sun, the Earth travels about 19 miles in a second of time. During the same interval the Sun pulls the Earth toward him about *one eighth of an inch.* The power exerted to produce this insignificant change of direction is so enormous that if the solar gravitation were to be replaced by steel telegraph wires they would have to be attached to the entire Sunward side of the Earth, considerably closer together than the stalks in a flourishing wheat field. If the bond con-

sisted of a single cast-iron rod, it would have to be thicker than the Earth itself in order to stand the strain. Yet the mutual attraction of the two bodies keeps them together without any visible bond.

Professor Duffield says of this law:

"We cannot but regard it as the most important truth in the whole book of Nature, and its discovery as the most interesting event in the history of physical science. As there is but one material Universe, and the law of gravitation solves the enigma of its structure, no other problem of equal interest and importance can ever occupy the attention of the student of Nature."

The above quotation, while paying a just tribute to Newton's discovery, really overrates the scope and importance of the law of gravitation. As Ernst Haeckel says:

"Newton had the immortal merit of establishing the law of gravitation and embodying it in an indisputable mathematical formula. Yet this *dead mathematical formula*, on which most scientists lay great stress, as so frequently happens, gives us merely the *quantitative* demonstration of the theory; it gives us no insight whatever into the *qualitative* nature of the phenomena. The action at a distance without a medium, which Newton deduced from his law of gravitation, and which became one of the most serious and most dangerous dogmas of later physics, *does not afford the slightest explanation of the real causes of attraction*; indeed it long obstructed our way to the real discovery of them."

The fact is that we are yet groping almost in the dark, and need a second Newton to tell us *why* the law of gravitation acts as he proved it to act.

PRECESSION AND NUTATION

In Chapter XII the slow reeling of the Earth's axis was described, without any explanation except the remark that it was allied to the wabbling of a child's spinning-top. As the phenomenon is one of the results of the law of gravitation, and

was first explained by Newton, a few words concerning its cause may not be out of place here. It should be remembered that the intensity of the Sun's attraction on a planet varies with the *square* of the distance. And it should not be forgotten that it acts independently on each and every individual atom composing the planet. An atom at the planet's centre is attracted *less* than an atom on the surface *facing* the Sun, and is attracted *more* than an atom on the surface *away from* the Sun. The difference in intensity produces the same result as though the nearest atom was *attracted*, and the farthest atom was *repelled*. In a perfectly spherical planet these differences would neutralise one another, and the effect would be the same as though all the atoms were at the centre of the planet. When the planet's equator is bulged out by rotation, the effect is the same, *providing* that the equator of the planet coincides with the plane of its orbit. *But* when the planet's equator is tipped up at an angle with the plane of the orbit (as is the case with our Earth), the *relative* attraction and repulsion, on the equatorial bulging, tend to reduce the angle at which the equator is tipped. The rotation of the planet, however, modifies the movement, so that (in summer and winter) an atom on the surface, at the equator, makes a lower curve and crosses the ecliptic a trifle behind the place where it would otherwise have crossed. This of course has the effect of making the polar axis reel slowly back, as already described. The effect is trifling, but cumulative, so that in the course of time the axis wabbles completely round. In the case of our Earth the process is greatly helped by the attraction of the Moon, yet it is so slight that it takes 26,000 years for the poles to make one wabble. At the equinoxes the action ceases, so that the circles described by the polar axis have a tremulous or wavy outline. As the Moon's orbit is a little inclined to the Ecliptic and has a "precession" of its own, another irregularity is produced every 19 years. These two irregularities in the Earth's precession are together known by the name of *nutation*.

CAUSE OF REPULSION

At first sight, the theory of gravitation does not seem to explain such phenomena as the *solar flames* and *corona*. These, and especially the latter, are evidently acted upon by a repellent force of enormous intensity. The explanation seems to be that radiant light tends to push away any substance that it strikes. In large bodies this repulsion is very small when compared with the force of gravitation. But the former acts according to the surface, and the latter to the mass. As bodies decrease in size, the repellent force of light decreases by the *square*, while the force of gravitation decreases by the *cube*. On extremely small particles gravitation is overpowered by a continuous repulsion two, ten, or twenty times as great, according to their size. They are therefore driven off like a bullet out of a rifle, only hundreds of times more rapidly.

Corona. — In the case of the corona, the eruptive particles are so minute that they appear to be driven clear away into interstellar space. On the way, some of them are intercepted by the planets. As they are charged with negative electricity, and the planets are huge "electrical machines," they arrange themselves according to the lines of force, and produce such electrical phenomena as the Zodiacal Light, the Gegenschein, the Aurora Borealis, etc. All the luminous stars send off similar negatively electrified particles, and when these, in their travels, come across a large mass of uncompressed matter, they cause its surface to glow like the rarefied gas in a vacuum tube. This appears to be the reason why nebulæ are luminous, though cold with the fearful cold of interstellar space.

Solar Flames. — In the case of the solar flames, the eruptive particles are probably larger, and therefore come to a standstill sooner or later. They are then buoyed up, not by an atmosphere, as our clouds are, but by the pressure of light radiating from below. If they join together to form larger particles, they fall back to the surface of the Sun, like the raindrops from our watery clouds.

A WREATH OF SMOKE

Sometimes, on a quiet evening, just before sundown, when hardly a breath of air was stirring, I have watched the blue rings and spirals of tobacco-smoke, slowly curling, twining, and eddying in the level glints of dying sunshine.

Now if you will imagine that the atoms of carbon in that wreath of tobacco-smoke are mighty suns in every stage of solar life, — from the spiral nebulæ of solar infancy to the dark, cold, and lifeless wrecks of superannuated suns, — then the curling and eddying smoke will represent the Universe.

For the great telescopes of our observatories show us star-clusters and nebulæ extended through space in gigantic rings, eddies, and spirals. If we could watch this celestial cloud of smoke for a few millions of years, it is almost certain that we should see these curves and spirals change from form to form like wreaths of smoke. Through all eternity the star-dust of which the Universe is composed is eddying and circling through space that has no limits.

And the very same laws which regulate the curling of the blue tobacco-smoke regulate the eddying and circling of the innumerable nebulæ, suns, and worlds which compose our mighty COSMOS.

NOTE. The laws briefly dealt with in the above three chapters are more fully discussed and illustrated in Sir George Airy's "Popular Astronomy," which was written for non-mathematical readers; in George C. Comstock's more recent "Textbook of Astronomy;" and in many other works.

CHAPTER XVI

ANCIENT COSMOGONIES, AND THE NEBULAR HYPOTHESIS

"In the intellectual infancy of a savage state, Man transfers to Nature his conceptions of himself, and, considering that everything he does is determined by his own pleasure, regards all passing events as depending on the arbitrary volition of a superior but invisible power. . . . After Reason, aided by Experience, has led him forth from these delusions as respects surrounding things, he still clings to his original ideas as respects objects far removed. . . . But as reason led him forth from fetishism, so in due time it again leads him forth from star-worship. . . . Philosophically speaking, he is exchanging, by ascending degrees, his primitive doctrine of arbitrary volition for the doctrine of law."
— *Dr. J. W. Draper.*

FACTS VERSUS THEORIES

THE human race is not old enough to have watched the development of suns and worlds to any appreciable extent. We cannot therefore *know* for an absolute certainty that such a process is at work throughout the Universe. Yet thinking men are naturally led, by their earthly experiences and celestial observations, to *believe* in such a development, and to theorise as to how the Universe has reached its present condition. They have even gone beyond the present, and speculated as to the changes which it will undergo in the future.

Even a false theory has its value as a stepping-stone to lead to a true one. It is well, therefore, to theorise even where we have no direct method of proving the truth or falsity of our speculations. When a theory gives a reasonable explanation of observed phenomena, it must have some truth in it. And when it not only explains all known phenomena, but also enables us to discover and explain fresh ones, we may regard it

as a valuable help for the upbuilding of the Temple of Knowledge.

Still it is well for us to remember that an unproved theory is not necessarily a permanent part of that Temple of Knowledge. It may be only a piece of scaffolding that will have to come down when the building is further advanced.

One of the great troubles in the past has been the tendency to mistake unproved theories for known facts, and to stretch, twist, or ignore all facts which refuse to fit in with them. This is evidently a serious mistake. As Sir William Crookes said at Berlin, a short time ago:

> "It must never be forgotten that theories are only useful as long as they admit of the harmonious correlation of facts into a reasonable system. Directly a fact refuses to be pigeon-holed, and will not be explained on theoretic grounds, the theory must go, or it must be revised to admit the new fact."

With this necessary warning I will now proceed to outline a few of the theories which have been held with regard to the past, present, and future history of the Universe.

HISTORICAL SPECULATIONS

There are in existence several different classes of what profess to be histories of the Universe in general and of our World in particular. Some of them have come down to us from prehistoric times, while others are quite modern. They differ so much from one another that it is evident they cannot all be historical. If one is true, the others must be more or less fictitious.

Some of the more ancient of the "historians" professed to start from the very beginning of things, although they found it a difficult thing to do. They began either with a primeval Chaos that always existed, or with a world-egg that no hen ever laid. Out of one of these they evolved the Earth and all that is therein, along with such trifles as the Sun, Moon, planets, and stars.

The more modern ones do not profess to know of any original Chaos, and they doubt the veracity of the primitive-egg story. They modestly content themselves with stating what they believe to have been the course of events since a certain time, beyond which they admit that they have no direct knowledge. And as far as possible they adopt those theories which appear to be supported by evidence, and to be in harmony with the laws of Nature as we know them here and now.

These different "histories" may be more or less definitely divided into the following four classses.

I. Primitive Creationism.
II. Pseudo Creationism.
III. Evolutionary Creationism.
IV. Modern Evolutionism.

I must here content myself with giving a very brief sketch of the leading varieties of these classes, beginning with the various forms of Creationism, which I have divided into Primary, Secondary, and Tertiary.

I. PRIMITIVE CREATIONISM (PRIMARY STAGE)

In early times, when unenlightened men first began to speculate as to the origin and history of the World and its surroundings, they found no one to tell them where the Earth had come from or how it had come into being.

The wise men of each tribe naturally had to answer many inquiries on the subject. If they had frankly admitted that they did not know the origin and destiny of all things, they would have lost their reputation for wisdom. So it was absolutely necessary for them to invent some story which, if it did not satisfy the mind of a child, would at least put a stop to its questions. This is probably the way in which all creation stories have originated, fresh details being gradually, and often unconsciously, added by successive generations.

From their own limited observations and experiences, these primitive men naturally inferred that the World could not always have existed as they found it. They concluded that it

must — some time, some where, and in some manner — have been either hatched or born. The only other explanation they could think of was that it might have been made by the Father of the Gods, for his own amusement.

As a rule the ancients were entirely ignorant of all except their immediate surroundings. This ignorance compelled them to view all things from a *flat-world standpoint*, which naturally and necessarily decided the character of their speculations on the origin of things in general. Having no one to tell them the facts of the case, they gradually evolved from their own inner consciousness a number of mythical histories whose ephemeral nature fitted in with their insignificant Cosmos.

The best known of these, so far as our part of the World is concerned, is an old Semitic legend, the modern form of which has been poetically narrated by Milton in his "Paradise Lost."

According to this account the World (including its attendant Sun, Moon, and stars) is a manufactured contrivance, invented and constructed by one who is known as the Architect, or Creator, of the Universe. Although the account professes to start from the beginning, it leaves the origin of the Creator himself in the primeval darkness, and even intimates that he had no origin, but always existed.

This Architect of the Universe is said to have "created" the World and its appurtenances. This prodigious work having been accomplished in six days, the Creator, we are told, "rested on the seventh day, and was refreshed." He now keeps it in existence and repair, and personally superintends everything that takes place on it.

Owing to the machinations of an ambitious and unscrupulous servant, whom he had himself brought into existence, things did not run smoothly in the newly created World. Its history (past, present, and future) embraces six thousand years of strife and one millennium of peace, corresponding to the six days of work and one of rest. At the close of the seven thou-

sand years the World and its Sun, Moon, and stars will be destroyed, and will be succeeded by "a new Heaven and a new Earth," to endure for ever.

II. PSEUDO CREATIONISM (SECONDARY STAGE)

The above is only one out of a number of primitive creation stories. In the course of time these childlike "histories" became looked upon as not only true but also "inspired." It was actually made a punishable offence to doubt their truth and inspiration. So, when men came to know something as to the actual dimensions of the Universe, and the relative importance of the Earth in that Universe, they recognised the improbable nature of these stories, yet hesitated about rejecting them as untrue and uninspired. The accounts were therefore "spiritually interpreted," to fit in with the new order of things. In some cases considerable ingenuity has been used to accomplish this. For example, when Astronomy had to be accepted, the seven thousand years of strife and peace were declared to refer to our World alone. When Geology had to be accepted, the seven days of creation and rest were "spiritualised" into meaning seven immense periods of time, long enough for suns and worlds to develop out of "fire-mist." The inconvenient fact that the Sun and stars were treated as mere appendages of the Earth, was explained as a "pious fraud" on the part of the inspired writer, rendered necessary by the ignorance of his readers.

Some people still accept these stories as true history. Others have forced themselves to the curious conclusion that they are not true historically, but that they are allegories, containing spiritual truths, perceptible only to those who are spiritually minded. All intelligent and well-informed people now know that these accounts are simply primitive speculations about the unknown past. But many of them refrain from hurting the feelings of others by openly saying so.

III. EVOLUTIONARY CREATIONISM (TERTIARY STAGE)

Among those who have rejected *Creationism* in both its *primary* and *secondary* forms, there are many who still adhere to it in an attenuated *tertiary* form. For want of time or lack of inclination to formulate a better and truer theory, they take it for granted that in a very remote past an Infinite and Eternal Being created an all-pervading *substance*, or *matter* out of nothing, and endowed it with certain permanent qualities and energies. He then allowed it to evolve without any further interference. The resulting physical and chemical movements of this matter have since produced the Universe as we know it.

Some, however, think that at one stage in each world there was a second creative act, — the introduction of organic life in its lowest form. From this primitive single-celled organism all the various forms of animal and vegetable life have since developed by natural laws.

Another interference with mundane events is believed in by some, — the implanting of an immortal soul in man after his body had sufficiently developed by the operation of natural laws. This immortal soul was then left to work out its own salvation or condemnation, without interference.

This tertiary and evolutionary creationism is upheld, in one or other of its forms, by a more intelligent class of people than those who are still in the primary and secondary stages, but it appears to share with those beliefs the disadvantage of not being either reasonable or true.

However, the truth itself is so astounding to finite creatures like us, and long-inherited prejudices are so strong, that the majority of people are not yet able to grasp or ready to receive it. In the meantime this evolutionary creation-story serves very well for a temporary basis on which to build a truer and more reasonable history of the Universe. It will be thrown away as soon as it has outgrown its usefulness, and the superstructure can then be fitted on to the eternal foundation of actual fact.

THE ORIGINAL NEBULAR THEORY

On the basis of a single creative act, Kant, Laplace, and Herschel I. founded their celebrated Nebular Theory, which first attracted notice about the end of the eighteenth century.[1] It is rather remarkable that these three great men arrived at practically the same conclusions by independent and entirely different routes.

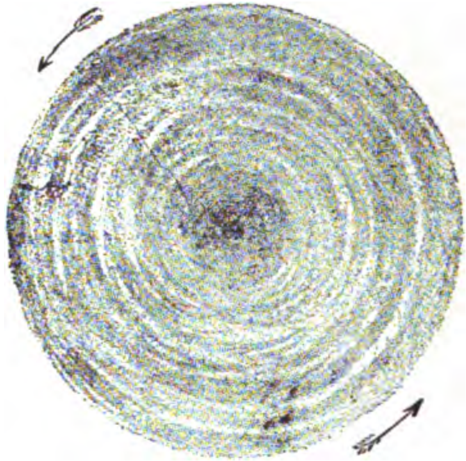


FIG. 86. — ORIGINAL NEBULA, AFTER ITS ROTATION HAS PRODUCED A DISC-LIKE FORM

Immanuel Kant[2] was led to it in his youth by abstract philosophical speculations. He outlined the theory in a work which was published in 1755, but as it did not excite any interest, he turned his attention to other speculations.

Pierre Laplace[3] was led to its consideration by mathematical

[1] Kepler and Tycho Brahe had previously speculated that the Sun and stars were condensations from celestial vapours.

[2] Born in 1724; died in 1804.

[3] Born in 1744; died in 1827.

reasoning, in middle age, and published it in a modest footnote in his "Système du Monde," 1796.[1]

Sir William Herschel[2] was led to it by his lifelong telescopic observations. He discussed it in his papers to the Royal Society.

The assumption was that "in the beginning" an inconceivably vast and attenuated mass of intensely heated gas was

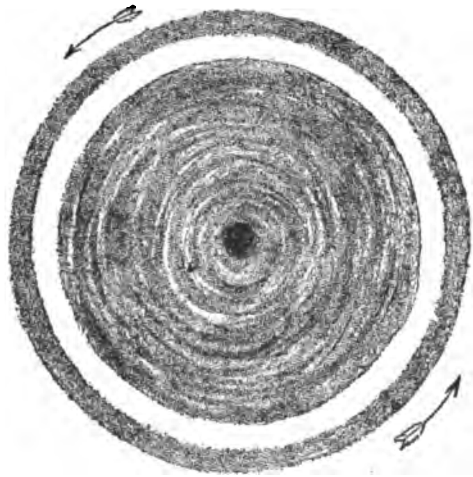


FIG. 87. — NEBULA WITH OUTER RING, LEFT BEHIND BY CONTRACTION AND CONSEQUENT QUICKENING OF ROTATION

created and put in motion. This original motion led — without any further interference — to its gradual condensation into a number of rotating lens-shaped nebulæ of thin gas. One of these has since shrunk and developed into our Solar System, others have condensed and developed into the stellar systems which surround us, and thousands (having for some reason failed to develop) still exist as glowing gaseous nebulæ. They

[1] He suggested it cautiously, "avec la défiance que doit inspirer tout ce qui n'est point un résultat de l'observation ou du calcul."

[2] Born in 1738; died in 1822.

all move according to the natural laws originally imparted to matter by the Creator, and eventually discovered by Kepler, Galileo, and Newton.

As one of these primary rotating nebulæ (subject to the mutual attraction of its own particles) gradually condenses into a spheroidal form, it naturally increases in density and speed

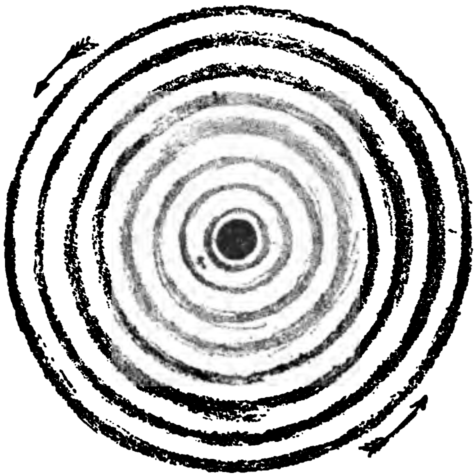


FIG. 88. — CENTRAL CONDENSATION SURROUNDED BY RINGS

of rotation. Much of its energy is also turned into heat, which radiates into space.

The tendency of every moving body to continue in a straight line (First Law of Motion) produces a centrifugal force which increases with the increasing speed of rotation. At last the equatorial part of the spheroid breaks away in a ring, which may continue to rotate around the shrinking central body. Generally, however, it breaks up into a secondary rotating spheroid, or *planet*, which continues to revolve around the primary one, or *sun*. Each planet goes through the same process of condensation, throwing off similar rings, which

generally collapse into tributary *satellites* or *moons* (see Figures 86 to 90).

In all these secondary and tertiary bodies the original heat is gradually dissipated by radiation into outer space. The later rings are smaller than the earlier ones, and give rise to smaller planets and moons, which go through the various stages more rapidly than the larger ones.

In time the formation of rings ceases, but the central spheroid continues to decrease in size and increase in density. Although

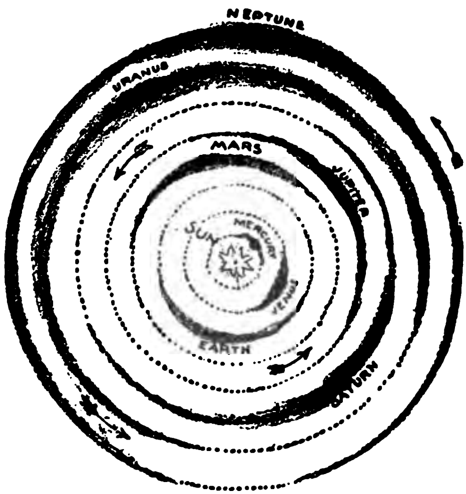


FIG. 89.—RINGS COLLAPSING INTO PLANETS, AND CENTRAL CONDENSATION TURNING TO A LUMINOUS SUN

still gaseous, it has long ceased to be a glowing transparent nebula, and is a compact bluish-white sun, radiating an immense amount of light and heat into space.

Later on, its colour changes to a yellowish white, and afterward to yellow. The radiation of heat into outer space goes on continuously, so that in time it cools off to a reddish tinge. The colour deepens to crimson and gradually fades away. The star liquefies and then becomes solid. The crust no longer

glows with light and heat, so that the star ceases to be visible from outer space.

Meanwhile the various worlds to which it has given rise have cooled off, become liquid, crusted over, and finally solidified. Life has made its appearance on their surfaces, developed, flourished, and died away in the growing cold. They are now dead worlds revolving about a dying sun.

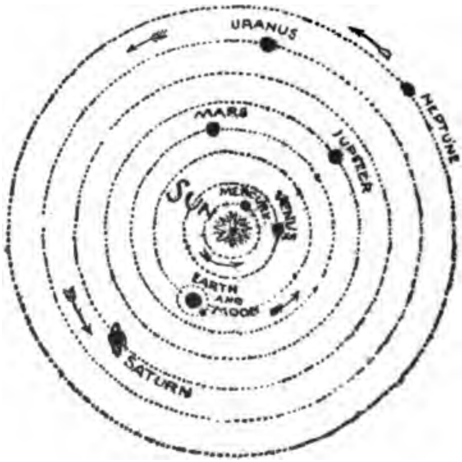


FIG. 90. — SOLAR SYSTEM AS IT IS NOW

In the course of millions of years the sun itself cools to its centre, and shrinks till it is but a shadow of its former self. All forms of energy die away, the times of rotation of the planets and moons become equal to their periods of revolution, and the entire system is dead and cold.

Lord Byron once wrote, of this period:

> "I had a dream which was not all a dream.
> The bright Sun was extinguished, and the stars
> Did wander darkling in the eternal space,
> Rayless and pathless, and the icy Earth
> Swung blind and blackening in the moonless air."

The other nebulæ which surrounded it have passed through the same stages and are also dead. The Universe is one vast cemetery of dead suns and worlds.

"Time was, time is, and time shall be no more."

Such is the evolutionary history of our Universe which has been theoretically built up on the most modern form of Creationism. It is not all true, yet it probably contains more truth than any of its predecessors. And it is perhaps about as near the truth as the majority of us are able to get without being overwhelmed by the awful realities of eternal time and infinite space.

Many of those who pursue the truth wherever it may lead them, regardless of prejudices and consequences, have changed and enlarged the original Nebular Theory to make it fit in with the discoveries of the nineteenth century. When thus changed it is no longer in the third stage of Evolutionary Creationism, but rests entirely on the fourth and last basis of Modern Evolutionism. It will be dealt with in Chapter XVIII.

CHAPTER XVII

THEORIES AND DISCOVERIES MODIFYING THE NEBULAR HYPOTHESIS

"We must bear in mind that scientific hypotheses as to the underlying causes of phenomena are subject to the law of evolution, and have their birth, maturity, and decay. Theory necessarily succeeds theory, and while no hypothesis can be looked upon as expressing the whole truth, neither is any likely to be destitute of all truth if it sufficiently reconciles a large number of observed facts.

"The notion that we can reach an absolutely exact and ultimate explanation of any group of physical effects is a fallacious idea. We must ever be content with the best attainable sufficient hypothesis that can at any time be framed to include the whole of the observations under our notice. Hence the question, 'What is electricity?' no more admits of a complete and final answer to-day than does the question, 'What is life?' Though this idea may seem discouraging, it does not follow that the trend of scientific thought is not in the right direction. We are not simply wandering round and round, chasing some illusive will-o'-the-wisp, in our pursuit after a comprehension of the structure of the Universe. Each physical hypothesis serves as a lamp to conduct us a certain stage on the journey. It illuminates a limited portion of the path, throwing a light before and behind for some distance, but it has to be discarded and exchanged at intervals, because it has become exhausted and its work is done." — *Professor J. A. Fleming.*

SINCE the original Nebular Theory, outlined at the close of the preceding chapter, was formulated by Kant and Laplace, great additions have been made to our knowledge of natural laws. And these additions have led to important modifications of the theory.

Some of the most important of these modifying discoveries and theories will now be briefly sketched. The reader is particularly desired to bear in mind Professor Fleming's words as given at the head of this chapter.

MATTER AND ETHER

Although it cannot be proved, it is now generally agreed that substance, or matter, exists in two forms, one of which has many subdivisions while the other appears to be homogeneous.

I. The first and most obvious division contains all forms of what may be termed *ponderable matter*, or, for convenience, simply *matter*. It includes all kinds of substance which are obvious to our senses. All *solids*, *liquids*, and *gases* belong to this division.

This sensible matter is supposed to consist of a variety of very small but perfectly distinct *atoms*. Those substances which are built up entirely of one kind of atom are known as *elements*, while those containing two or more kinds of atoms are known as *compounds*. It possesses such characteristics as go by the name of gravity, inertia, molecular heat, and chemical affinity.

II. The other form of substance may be termed *ethereal matter*, though it is commonly known as *ether*.[1] It does not consist of a variety of atoms, like the ponderable matter just mentioned. It is practically imponderable and is absolutely imperceptible to the senses. We have therefore only indirect proofs of its existence.

According to one of the most modern theories concerning this ether it is composed of particles which are very much smaller than atoms and are all exactly alike in every respect. These are supposed to be so crowded together that they act like one continuous substance. It has also been likened to an inconceivably thin elastic transparent jelly, filling all space not occupied by ponderable matter. It even fills the spaces between the atoms of the latter. Its existence appears to be proved by the action of gravitation across apparently empty spaces, and also by its wave-like movements, which are recognisable as radiant energy, in the forms of chemism,[2] light, heat, electricity, and magnetism.

Although we do not *know* that the above theory is correct, we are compelled, by reasoning on observed phenomena, to *believe* that, in one or other of its two forms, this indestructible

[1] Not the bottled ether of the chemist, but the *luminiferous ether* of the astronomer.

[2] Producing chemical action. It is also known as actinism.

substance, or matter, fills all the infinity of space, without any void whatsoever.

ATOMIC THEORY

The science of chemistry deals with ponderable matter only. It has ascertained by experiment that all the varied substances known are composed of about 80 "elementary" forms of matter. These exist either separately, as *elements*, or combined, in certain fixed proportions, to form chemical *compounds*. And it has explained the observed phenomena of chemical combination by what is known as the Atomic Theory, formulated by Dalton in 1808. This theory is that each of the elements is composed of separate and infinitesimal *atoms*. These are all supposed to be exactly the same in size, weight, shape, and properties, but to be entirely different, in size, weight, shape, and properties, from the atoms of any other element. These atoms may combine to form *molecules*, but seem to be incapable of further analysis.

PERIODIC SYSTEM OF ELEMENTS

Although one element cannot be changed into any other element, yet the different elements do not appear to be absolutely independent of one another. When they are arranged according to their combining weights, they fall naturally into family groups, reminding one of the octaves of music, where the eighth notes are related to one another. It is probable, therefore, that the elements are not ultimate unchangeable forms of matter, but that their atoms consist of variously arranged groups of one primitive form of matter. This, when uncondensed, may possibly form the substance of the luminiferous ether.

THE LAW OF SUBSTANCE

One of the most far-reaching of modern discoveries is that of the Law of Substance, commonly known as the Law of the Conservation of Matter and Energy.

Indestructibility of Matter. — One half of this law of sub-

FIG. 91. — DUMB-BELL NEBULA

Lick photograph.

stance was discovered much earlier than the other half, and is still known as the Law of the Persistence or Indestructibility of Matter. It was worked out experimentally, with the balance, in the laboratory of Lavoisier, as early as 1789. This first half of the law affirms that no substance is ever created or destroyed; that the Universe always contains exactly the same quantity of matter; and that chemical processes do not increase or decrease its quantity, but merely change its condition.

The modern science of Chemistry has been largely built on this half of the law of substance, and it is now accepted by all thinking men.

Conservation of Energy. — The other half of the law of substance is known as the Law of the Persistence of Force or Conservation of Energy. It was worked out experimentally, in the workshop of Robert Mayer, in 1842. This second half of the law of substance affirms that no force is ever created or destroyed; that the Universe always contains exactly the same amount of energy; and that chemical and mechanical changes do not increase or decrease its amount. They merely change its condition from *potential* to *actual*, or from *actual* to *potential*, leaving the sum total of the two forms of energy eternally the same.

The physical sciences have been largely built on this half of the law of substance, and it is now adopted (either as a fact or as a working hypothesis) by all thinking men.

Actual energy manifests itself in several different ways, and one kind of it can readily be changed into another. Sound, heat, light, chemical action, electricity, magnetism, etc., are all manifestations of energy, and any one of them can be converted into any other without actual loss of energy.

Some one may here say, "That sounds like perpetual motion, which we know to be an absurdity."

It is true that perpetual motion is an absurdity so far as machinery constructed by man is concerned. That, however, is not because any of the energy is destroyed, but because it is turned into a form which is not available to us. It still exists,

and accurate measurement will show that there is no loss of energy whatever.

All forms of energy are available to Nature, so that the Universe as a whole is not only a "perpetual-motion machine," but is the only one that can possibly exist.

SPECTROSCOPIC DISCOVERIES

The discovery of the dark lines in the solar spectrum, by Wollaston and Fraunhofer, and their explanation by Kirchhoff and others, after fifty years of study, have put the atomic theory on a solid basis, and given an immense help in solving the riddle of the Universe. Kirchhoff's discovery, in fact, deserves to rank with the discovery of the law of gravitation by Newton. While the one enables us to weigh the suns and worlds in a balance, and to find out their past, present, and future movements, the other tells us what they are made of and the condition they are in. It also enables us to detect celestial phenomena and movements that the telescope by itself fails to reveal. These achievements have, however, been already described in former chapters, so need not be further dwelt on here.

KINETIC (OR VIBRATORY) THEORY OF SUBSTANCE

It is now concluded that all the different forms of energy — gravitation, sound, heat, light, chemical action, electricity, and magnetism — are only different manifestations of one primitive force. This is commonly conceived to be a vibratory motion of the atoms of matter dancing to and fro in empty space, and influencing one another at a distance without any medium.

When this theory is examined, however, some parts of it prove not only mysterious, but improbable, if not impossible. We can find no satisfactory answer to the question, How can a thing act where it is not present?

PYKNOTIC (OR CONDENSATION) THEORY OF SUBSTANCE

To overcome this objection it has been suggested that all space is filled with a simple primitive continuous substance, which has a tendency to contract or condense around infinitesimal centres. These centres of condensation are the *atoms* of ponderable matter, and they are supposed to float in the uncondensed matter, which goes by the name of *ether*. The condensation of the atoms causes a stretching of the surrounding ether. The efforts of the atoms to complete their condensation are therefore opposed by the resistance of the ether to the further increase of its strain. The result is the accumulation of an immense amount of potential energy around the atoms, and of actual energy in the ether. These two forms of energy are continually varying, but the sum of them is ever the same. They manifest themselves as light, heat, gravitation, and all the other modes of motion with which we are acquainted, and thereby produce all the varied phenomena of Nature.

These two theories of substance are now being tried in the crucible of experiment and observation. Fresh facts are being discovered every day, and a satisfactory and comprehensive theory will probably be constructed before very long.

ELECTRO-MAGNETIC THEORY OF LIGHT

Until 1872, "chemism," light, heat, electricity, and magnetism, were almost universally regarded as separate and distinct entities. We now look upon them as merely sensations or effects due to *one solitary form of radiant energy*, which is given off by all radiant suns, and manifests itself differently according to the way in which we observe it.

According to Maxwell's electro-magnetic theory of light (which is now generally accepted), heat, light, magnetism, etc., are simply different manifestations of *electricity* generated and sent out by the huge electrical machines which we know as suns or stars. They are, in fact, due to stresses and strains in the luminiferous ether.

It will be seen that the tendency now is not to seek for mechanical explanations of electrical phenomena, but to look for electrical explanations of mechanical phenomena.

ULTRA-ATOMIC (OR ELECTRONIC) THEORY

Kathode Rays.—If a wire which carries a current of electricity be cut in two, and the ends kept apart, the flow is of course stopped. But if the cut ends (or terminals) are inside a closed glass vacuum-tube, the current leaps across the almost empty space, and the tube is filled with a phosphorescent glow. Sir W. Crookes, and Professor Thomson, after years of experiment with these vacuum-tubes, concluded that this cold light is due to a torrent of small *negatively electrified particles* of *radiant matter*, chipped off the "kathode" or negative terminal.

These *kathode particles* resemble ordinary matter in possessing inertia, and will turn a toy windmill when they strike it. By allowing some of them to pass through a slit in a mica diaphragm, and then to skim along the surface of a screen coated with zinc sulphate, their course becomes visible (in the dark) to the naked eye. Ordinarily the particles travel in a straight line, so that their course resembles a straight jet of steam. But when a magnet (or a *plus* pole) is brought near, the jet of luminous particles bends toward it, as a horizontal jet of water bends toward the earth. The amount of the deflection depends on the strength of the attracting current, the mass of the particles, and the speed at which they travel. It has thus been ascertained that the particles are from 700 to 1000 times less (in mass) than an atom of hydrogen, and that they travel at a speed comparable with that of light. The torrent gives a negative electric charge to any bodies it may strike, and it appears to be virtually an electric current. Metals are transparent to it, and even after passing through them it affects a photographic plate more powerfully than ordinary light.

Röntgen or *X Rays.*—Any object struck by these kathode particles gives off what are thought to be *invisible ether waves.*

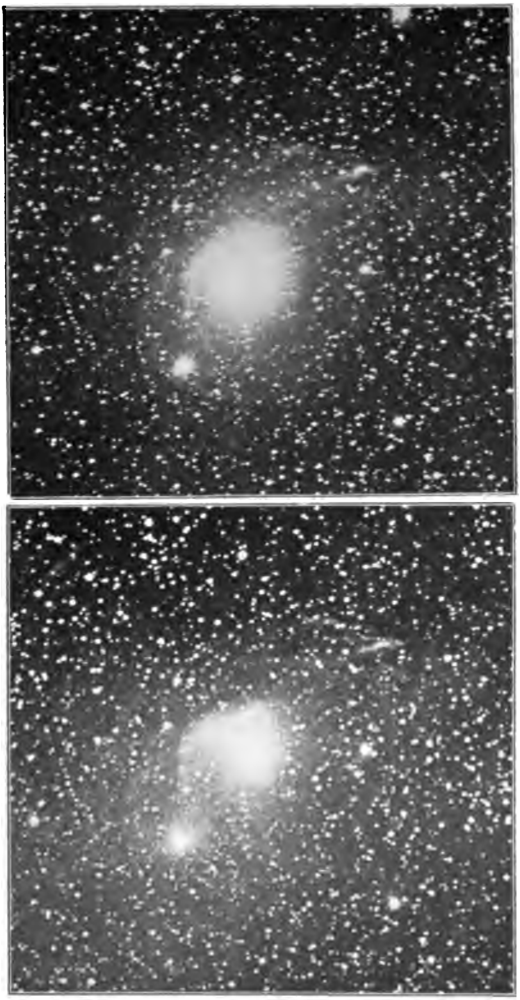


Fig. 92. — Nova Persei, 1901. Showing Movement of Surrounding Nebulosity

Lick photographs.

(a) Nov. 7–8, 1901. Exposure 7 h. 19 m.
(b) Jan. 31 and Feb. 2, 1902. Exposure 9 h. 45 m.

These are commonly known as *Röntgen* or *X Rays*. They radiate from their source in straight lines, and are *not deflected* by a magnet or electrical field. They can pass through wood, metal, leather, and flesh without losing their power of affecting a photographic plate. They do not impart negative charges to the bodies on which they fall, but they discharge charged bodies by making gases better conductors of electricity.

Becquerel Rays (*Alpha, Beta,* and *Gamma*).—Besides the two kinds of STIMULATED *radio-activity* just described, some forms of matter possess a SPONTANEOUS *radio-activity*. All compounds containing the heavy elements known as radium, thorium, cerium, and (perhaps) actinium, give out, continuously and spontaneously, three distinct kinds of radiant energy. These are known as—

Alpha, or *Atomic Rays*.
Beta, or *Kathodic Rays*, and
Gamma, or *Röntgen Rays*.

Alpha or Atomic Rays.—These are the most noticeable of the spontaneous radiations, and appear to consist of atomic projectiles shot out in all directions from the radio-active substances. They move in a straight line with a velocity of about 20,000 miles per second. They are not ordinarily drawn aside by a magnet or by an electrically charged body, but in a very strong electrical field they are deflected toward the *negative* pole. The direction and amount of this deflection, with a current whose intensity is known, prove that they consist of *positively electrified atoms* whose mass is two or three times as great as that of hydrogen atoms.[1] On account of their great size they cannot pass between the atoms of ordinary matter. They can therefore be stopped by a sheet of paper. They affect a photographic plate more slowly than the *beta* particles, but discharge electrically charged bodies more quickly.

[1] They may possibly be atoms of the newly discovered metal *helium*, whose atomic weight is four times that of hydrogen. This element is never found except in company with the heavy radio-active elements we are discussing, and its spectral line has been found in the gaseous emanations from radium.

Beta or Kathodic Rays.—These are identical with the kathode rays of the Crookes tube. They therefore consist of ***negatively electrified particles*** about 2,000 times smaller (in mass), than the *alpha* atoms. They travel in a straight line at about the speed of light. They can pass through a plate of platinum or an inch of solid iron, and then strongly affect a photographic plate. On account of their small size they cannot discharge electrified bodies so quickly as the more ponderous *alpha* projectiles.

Gamma or Röntgen Rays.— These are identical with the *x* rays of the Crookes tube. They are probably ether-waves caused by the breaking up of the atoms. They can pass through six inches of iron and then affect a photographic plate.

Of all the radio-active elements yet discovered, ***radium*** is by far the most active. It is indeed so active that its compounds are measurably warmer than surrounding objects. In the dark they give off a faint light like that of a glow-worm. When they are placed near a screen covered with zinc sulphide, the impact of the bombarding projectiles on the zinc crystals gives a display which (seen through a microscope) resembles a sky full of shooting-stars.

The available evidence seems to show that those elements whose atoms are very heavy and complex were built up under conditions very different from the present ones, and are now very slowly disintegrating, by stages, into lighter and simpler elements.[1] This would explain the apparently inexhaustible supply of energy possessed by the radio-active elements.

In this connection Professor R. A. Millikan says:—

"The disintegration of a gram of uranium, or thorium, or radium, sets free at least a million times as much energy as that which is represented in any known chemical change taking place within a gram weight of any known substance. The experiments of the last

[1] This would be analogous to the complex molecules which are built up by living organisms (at the expense of solar energy) only to disintegrate into simpler ones at the first available opportunity.

eight years have then marked a remarkable advance in science, in that they have proved the existence of an immense store of sub-atomic energy."[1]

Glowing metals and other hot bodies give off radiant matter somewhat similar to some of the forms described above. Cold metals do the same when they are exposed to ultra-violet light. It is possible that all forms of matter may emit similar particles all the time.

It would be absurd to suppose that these bodies can give out either radiations or particles continuously without any loss of energy or weight, but the loss may sometimes be so small that they may appear to do so. In some cases the radiations may have been previously received from the Sun, and the vibrations changed to a rate which our senses or instruments are capable of perceiving or registering.

The particles of which most radiant matter is composed are variously known as *electrical corpuscles*, *electrons*, *ions*, or *negative particles*. It is worthy of note that different substances do not give out different kinds of corpuscles, but that the latter appear to be all alike, whatever their source.

An atom of hydrogen is *the smallest of all known atoms*. In decomposing water by electricity, an atom of hydrogen carries a certain definite and indivisible charge of electricity, which is known as an *electron*. Now it has been found that one of our newly discovered corpuscles [although it is *from 700 to 1000 times less (in mass) than an atom of hydrogen*] carries the same amount of electricity. This, however, is always what is known as a negative charge. Positively charged corpuscles have not yet been discovered, and they probably do not exist in a free state.

It is possible that all the various forms of "elementary" atoms composing ponderable matter are built up of concentric layers of corpuscles, the layers being alternately positive and

[1] "Recent Discoveries in Radiation," *Popular Science Monthly*, April, 1904. Perhaps this advance will help to set at rest the long-standing dispute between the astronomers and the geologists as to the duration of geologic times.

negative. In this case we may assume that the outside layer is always composed of negative corpuscles, so that the atoms all attract one another at a distance, but mutually repel when close together, especially when they are of the same sign. For otherwise the atoms would mingle and lose their individuality. If this is so, then the vibrations which produce light, etc., are not vibrations of the atom itself, but of the electrons or corpuscles of which it is composed.

According to this Electronic Theory, electrons or corpuscles are the ultimate particles of which all kinds of atoms consist. The atoms themselves are "star-clusters" of electrons in stable orbital motion at planetary distances from one another. On this hypothesis a cluster of about 700 electrons forms an atom of hydrogen. An atom of oxygen contains about 11,200 of them. An atom of gold contains about 137,200. And so on.

It appears probable that, besides the corpuscles which are built up into atoms, there are such vast quantities of free negative corpuscles that they fill all space to saturation. If so, then the luminiferous ether itself consists of these electrons or negative particles.[1]

[1] This Electronic or Ultra-Atomic Theory appears to have needlessly alarmed many people, who think that it will lead to the overthrow of the Atomic Theory and of the Law of Substance. They may perhaps be set at ease by the following words by Sir Oliver Lodge, F.R.S., at the close of an article on "Radium and its Lessons." He says:

"Let me conclude by asking readers to give no ear to the absurd claim of paradoxers and others ignorant of the principles of physics, who, with misplaced ingenuity, will be sure to urge that the foundations of science are being uprooted, and long-cherished laws shaken. Nothing of the kind is happening. The new information now being gained in so many laboratories is supplementary and stimulating, not really revolutionary, nor in the least perturbing to mathematical physicists, whatever it may be to chemists; for on the electric theory of matter it is the kind of thing that ought to occur. And one outstanding difficulty about this theory, often previously felt and expressed by Professor Larmor, — that matter *ought* to be radio-active and unstable if the electric theory of its constitution were true, — this theoretical difficulty is being removed in the most brilliant possible way." — *Nineteenth Century Magazine*, July, 1903.

FIG. 93. — SPECTRA OF NOVA PERSEI, SHOWING CHANGES

Yerkes Observatory.

Feb. 27. Mar. 6.
Feb. 28. Mar. 15.
Mar. 28.

REPULSION OF LIGHT

It has been discovered, first by theory and afterward by experiment, that when the vibrations of light strike any object they push against it with a force which varies according to the *square* of its diameter. And as the attraction of gravitation, acting on the same object, varies as the *cube* of its diameter, it follows that, if the object is small enough, it will be violently repelled from the source of light.

These facts form a simple and sufficient explanation of many physical phenomena, both terrestrial and celestial, and have been several times alluded to in the preceding chapters.

EVOLUTION OF LIFE, ATOMS, AND WORLDS

About the beginning of the nineteenth century, Goethe, Lamarck, and some other naturalists rejected the theory of the special creation of the different species of plants and animals. They contended that all have developed, by natural means, from the simplest forms of life, which originally came from non-living matter. This development, they claimed, was carried on by means of the interaction of *heredity* and *adaptation.*

In 1859 Charles Darwin proved the truth of this theory of descent, as far as such a theory is capable of proof, and showed that it was caused by a *struggle for existence* and the resulting *natural selection* by the *survival of the fittest.*

The late Herbert Spencer first recognised that the same law of evolution dominates the entire Universe. He showed that its transformations are exhibited, not only by the Universe as a great whole, but in all its details. They can be traced in the Solar System, and in the inorganic Earth; in the organic world as a whole, and in each individual organism; in society at large, and in the individual mind. They are also clearly recognisable in all the products of social activity.

From suns and worlds to molecules and atoms, all things struggle for existence, and survive or perish according to their

fitness. The reason why atoms and suns are in a state of stable equilibrium that seems to be the result of mental contrivance is that all the forms which do not possess that "fitness to survive" are promptly changed into forms that are not mutually interfering. In both atoms and suns there is an unconscious struggle for existence leading to an equally unconscious survival of the fittest.

PRIMEVAL TIDES

The shape, size, condition, and movements of any heavenly body are due to the forces which act (or have acted) upon the *individual particles* of which it consists. The mathematical study of these forces has led to the discovery that the development of suns and worlds is largely controlled by tidal action while they are still in a gaseous or liquid-gaseous condition.

In a solar system like ours, and in a binary system or star-cluster, the various bodies are moving with a certain regularity along practically non-interfering lines. This is not the result of skilful manœuvring by clever world-pilots. There is no one steering them out of danger. Their apparent security is simply due to the fact that interfering movements soon lead to catastrophes which effectually remove the insecure members of the family circle, but leave the others alone. It is simply an instance of the struggle for existence and of the survival of the fittest.

But the sovereign suns which roam at large through space all appear to be flying at random. So far as we know they have no regular orbit, but each one is apparently dashing blindly in the direction of least resistance to the surrounding centres of attraction. They may be likened to a cloud of mosquitoes or a vast swarm of bees.

Let us suppose that two gaseous suns are approaching one another from opposite directions. Each one is sailing majestically along in a practically straight line, and at the same time is serenely spinning around on its axis.

If there were pilots on board, who could control them by

means of a steering-apparatus, they would probably get in a flurry sometimes, steer wildly, and cause a collision. But as there is no one in charge to make trouble, an "accident" of this kind seldom takes place.

It seems natural to suppose that if the two suns do not actually collide they will pass each other and go on their way as though they had never met. This is the case, indeed, when they are a great distance apart. But if they pass very near to one another the law of gravitation compels them to salute each other. Their original speed is added to by their mutual attraction. They swing in toward one another, pass like a flash, and go off on a curve which soon becomes practically a straight line.

So far the only effect noticed has been a change of direction. But there appear to be other changes produced. When the two bodies were making their bow to each other, the *central* particles in each of the suns were attracted *less* than the *nearest* particles, but *more* than the *farthest*. The intensity of the pull varies in the inverse ratio to the *square* of the distance (see Chapter XV). The result is the same as though the nearest and farthest particles in each body were strongly repelled from one another. The two suns therefore lose their original orange-shape (due to attraction modified by rotation) and become more or less the shape of a pear. After they have passed each other, never to meet again, they continue to rotate as before, and the small end of each pear-shaped star swings around as a mighty tidal wave. The centrifugal tendency is so strong that the two ends gradually draw the central matter to them, forming a dumb-bell arrangement which finally breaks in two. The result is that each star becomes a "binary" or double star, in which both of the partners rotate in the same direction as that in which the parent moved. The telescope and spectroscope show the heavens to be crowded with such binary systems. In some cases the rotation is so rapid as to show that the partners are still clinging together like Siamese Twins.

The binary system known as *V Puppis* appears to be in this stage of evolution. The combined mass of the two partners is equal to that of 66,000 worlds like ours, and they are still in a distended gaseous state. Yet they are shown to revolve (or rotate) in the remarkably short period of 35 hours.

The theory of tidal evolution (on which the above description of "puppation" is founded) was demonstrated mathematically by Professor George Darwin from an examination of the interaction between the tides and the motions of the Earth and Moon.

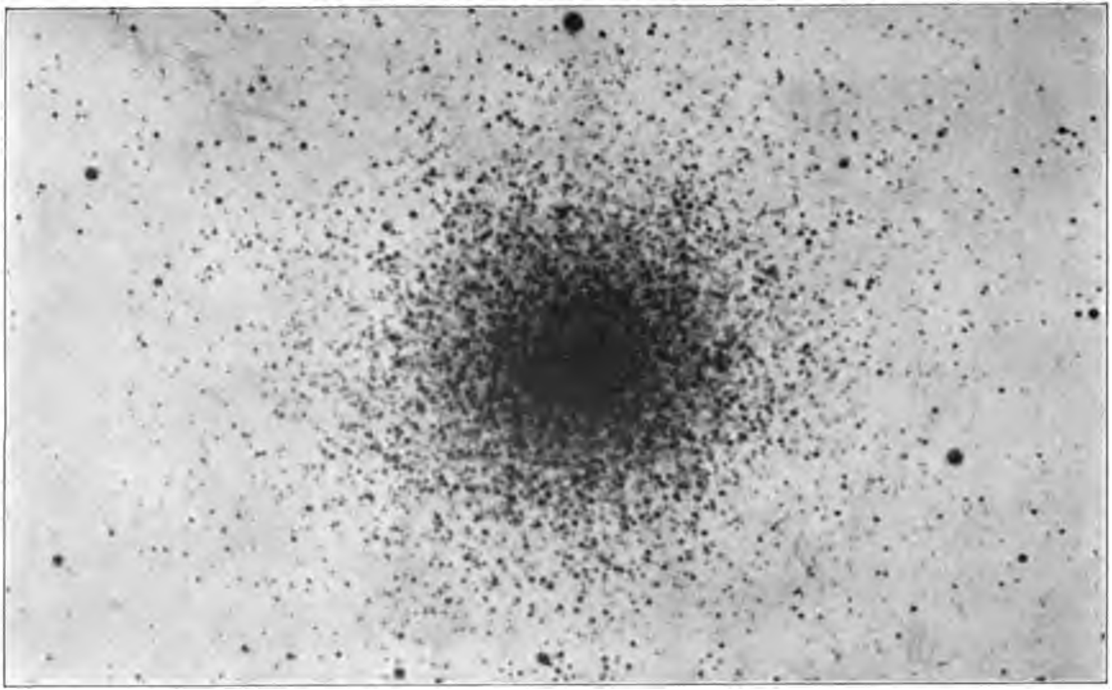


FIG. 94. — THE STAR-CLUSTER OMEGA CENTAURI

Harvard (Arequipa) photograph.

CHAPTER XVIII

MODIFICATIONS OF THE NEBULAR THEORY

"Worlds on worlds are rolling ever,
From creation to decay,
Like the bubbles on a river,
Sparkling, bursting, borne away." — *P. B. Shelley.*

"Without beginning, aim or end;
Supreme, incessant, unbegot;
The systems change, but goal is not,
Where the Infinities attend." — *G. Sterling.*

IMMORTALITY OF THE UNIVERSE

THE discoveries and speculations I have just sketched, and others which have not been mentioned, have led to some important modifications and developments of the original Nebular Theory.

Among other changes, the foundation of Creationism has been rejected by the foremost minds, so that the whole theory is evolutionary. We now recognise no beginning and acknowledge no end. We can conceive of no space which is not occupied by matter in one or other of its two forms. We can admit of no exhaustion of energy leading to a dead Universe. We have come to the conclusion that nothing exists apart from matter and its energies. Mind, in the form of desires and inclinations, exists not only throughout the animal and vegetable kingdoms, but likewise in so-called dead matter. Even the molecules, atoms, and corpuscles have a kind of sensation and will.

"FROM DEATH UNTO LIFE"

The secret of the perpetual youth of the Universe appears to lie in the fact that the millions upon millions of heavenly

bodies do not move in paths of eternal regularity, but that they interfere with one another. This causes their orbits to be changeable, and, to some extent, irregular. The result is that every once in a while two of them come into violent collision, thus changing a large amount of potential into actual energy.

If two trains travelling at the speed of a mile a minute were to meet "head on," it is obvious that an enormous amount of latent energy would be turned to actual energy. If they were travelling 750 times faster (which is the speed at which our Sun is going toward Vega), the amount of actual energy produced by the shock would be 540,000 times greater ($=750\times 750$). And if the two trains were to be loaded down till they each equalled our Sun in weight, the energy produced would be proportionately increased. It would be equal to that caused by a direct collision between our Sun and another star of the same mass and travelling at the same speed.

The result of such a collision could be calculated mathematically, but the most vivid imagination could not picture it. Yet there are suns many thousands of times larger, travelling at a speed many times as great, and apparently liable at any time to come together with a crash, or to glance by one another with a result almost as disastrous. In the event of such a collision the temperature of the colliding bodies would be raised many thousands of degrees. They would expand into a huge mass of thin gas, which would, in time, cool off to the temperature of space (probably about $-230°$ F.). That is to say, the old and feeble — perhaps dead — suns would spring into new youth and drift away as a more or less diffuse and shapeless mass of glowing gas. This would gradually assume the form of a rotating spiral nebula, and begin once more the great drama of evolution.

This picture is no freak of the imagination, but appears to be an illustration of an actual fact. In all probability such things have always been taking place, are taking place now, and will be taking place when our Solar System has for ever disappeared and been forgotten.

We thus see that the evolution of suns and worlds does not necessarily take place once and then cease. It is apparently repeated over and over again; here, there, and everywhere. As Ernst Haeckel says, "while the rotating masses move toward their destruction and dissolution in one part of space, others are springing into new life and development in other quarters of the Universe."

SOME NEBULÆ ARE COLD

The Nebular Theory of Laplace was that the nebulæ were extremely hot, and rotated in lens-shaped masses which threw off regular rings. It has since been modified for both theoretical and observational reasons.

In the first place it is evident that, however hot a thin nebula may be at its first formation (due to the collision of mighty suns), there is nothing to prevent that heat from radiating away into outer space. When it has done so there is no fresh supply of heat to draw from except that produced by the action of gravitation drawing its spirals back into condensed centres, and it takes millions of years for that to produce any great increase of temperature. So in the meantime it may be invisible except at the outer surface. There a rain of negatively electrified corpuscles (sent out by the myriads of radiant suns) probably causes it to glow with a cold light akin to many other corpuscular radiations.[1]

In the second place it has been found that the most common form of nebula seen in the telescope is not lens-shaped, but spiral. While some of the nebulæ (like the Great Nebula in Andromeda) seem to be condensing into a vast central globe surrounded by tolerably even rings, others (like the Spiral Nebula in Canes Venatici) appear to be condensing around a number of centres, as though forming a social system or star-cluster (see Figures 63, 64, and 85).

[1] Among these may be mentioned the Solar Corona, the tail of a comet, the Zodiacal Light, the Gegenschein, the Aurora Borealis and Australis, St. Elmo's fires, the phosphorescence of fishes and other animals, the kathode rays of our electricians, etc.

EVOLUTION OF SOLAR SYSTEM

When our Sun was in its first nebular stage (perhaps due to collision), it was probably a hot and more or less spherical mass of inconceivably thin gas, immensely larger than the whole Solar System is now. Its particles would then be so far apart that the most perfect vacuum we can produce would be dense in comparison. Seen from a great distance, it would probably resemble the symmetrical planetary nebulæ which are revealed by our telescopes (see Figure 99).

Presuming that this planetary nebula was not interfered with from outside, it would not lose its regularity of form, but would gradually condense and acquire a spiral structure. But if any wandering stars had happened to pass through it, it might for a time have assumed the torn explosive appearance of the great Trifid Nebula (see Figure 67), and if it had collided with a neighbouring nebula it might possibly have acquired an irregular form like that of the Great Nebula in Orion (see Figure 68), but of course it would have been on a much smaller scale. Unless very much scattered, however, the mutual attraction of its particles would, in the course of time, again bring about a regularity of form and structure.

When a cricket-ball is struck by a bat, the size, shape, and density of the two bodies, and their position, speed, and direction, determine the flight of the ball and the subsequent adventures it may meet with. In the same way the colliding bodies which we assume to have given birth to the nebulous mass under consideration must have received a certain *moment of momentum* which has produced every peculiarity now possessed by the Solar System which has developed from it.

After the explosive energy of the original collision had produced the hypothetical nebula, every gaseous particle in it was left at a certain temperature and in a certain position. It was also moving in a certain direction with a certain velocity. The varied and irregular nature of these movements led to innumerable collisions between the particles. Some of the energy pos-

sessed by the particles was thus turned to heat, which, like the original heat of the nebula, radiated away into outer space. The varied movements of the particles, and the resulting collisions, naturally ended in the survival of the movements which did not interfere with one another. The mass therefore gradually attained a rotating disc-like form, lying on a plane — and moving in a direction — determined by its original "moment of momentum." In this way every particle moved in the path of least resistance, and therefore with the least expenditure of energy.

By this time the temperature of the nebula was very much reduced by radiation into outer space. It was probably invisible except near the surface, where the radiant energy from surrounding suns made the light surface-gases glow with a cold radiance akin to that of the kathode rays of our vacuum tubes.

The dissipation of the original heat by radiation led to the contraction and condensation of the entire mass. The decrease in size of course led to an increase of the density and speed of rotation. As the speed was greatest toward the centre, a rotating and indrawing spiral was the result (see Figures 63 and 85).

The centre of this spiral became a vast condensation which, in the case of our System, drew to it the great mass of the nebula. Four important subordinate centres of condensation were also formed, as well as a great number of lesser ones. These centres gradually absorbed the nebulous matter around them, and thereby increased continuously in density.

At first these centres of condensation did not have any rotation except that due to the spiral indrawing revolution of the whole mass. That is to say, each subordinate centre rotated at the same speed that it revolved. But as its particles were drawn in toward the centre, the rotation grew more rapid, because they had a shorter journey to go and were nearer the local centre of attraction. All the subordinate condensations, therefore, acquired an ever-quickening speed of rotation in the same direction as the revolution of the whole system. In the case of the central condensation there would be no distinction between rotation and revolution.

As the particles in one of these condensations gradually fell in toward its centre, their friction with one another turned a large part of its energy into heat. So much heat was produced in this way that it could not all radiate into space. Its temperature, therefore, rose, slowly but steadily, till it glowed like a little sun.

As a result of the changes outlined in the preceding three paragraphs, the centres of condensation, though they decreased in size, continually increased in *density*, *speed* (of rotation and revolution), and *heat*.

So far we have theoretically traced the evolution of the original nebula into a system of thin, hot, and bright gaseous planets revolving around a huge gaseous centre. This central condensation was even hotter than the planets, and was destined in time to become a central sun, luminous with an inconceivable intensity of heat.

The small amount of nebulous matter which still remained, outside the planetary centres, was gradually drawn in by them in a spiral manner, and condensed into similar but smaller centres. They acquired the same peculiarities of revolution and rotation, and in fact repeated the original history of the whole system on a smaller scale. This appears to be the origin of the satellites which now attend the larger planets, and of the rings of Saturn, which consist of innumerable small satellites.

After a certain amount of condensation the production of frictional heat in each subordinate centre became less in amount. As the radiation continued unchecked, a maximum of heat was reached, and the satellites and planets then began to cool off. The smaller a body is, the larger becomes its surface in proportion to its mass. The satellites and smallest planets therefore cooled off the quickest. Their surfaces solidified and became solid rock. This, being a bad conductor of heat, somewhat checked their loss of heat by radiation, but did not altogether prevent it. In time they therefore became solid to the centre and gradually approximated to the temperature of outer space.

The larger planets are now going through the same cooling

and solidifying process. But the central Sun is still producing about as much heat by its contraction as it loses by radiation into outer space. It is still kept in an incandescent gaseous form by this heat, and the only elements in it which have reached a solid state are the carbon and silicon which are exposed to the cold of outer space above a certain elevation in its atmosphere of metallic gases. Their chilled particles are apparently frozen into solid incandescent beads that form the glittering clouds which we term the solar photosphere.

We thus see that the heat of the Sun is not due to combustion. In fact combustion is like organic life,—it cannot exist above or below a certain range of temperature. The heat of the Sun is at present far too great to allow a comparatively cold process like combustion to take place anywhere near it.

When the Sun formed the bulk of the original nebula its energy was all potential. Its circling particles have been falling ever since, as they "spirated" around the centre of gravity of the mass. Their friction in falling is the cause of all the heat, etc., which has since been produced and radiated. The same amount of heat is produced by the friction of adjacent particles, whether a body falls rapidly or slowly, directly or indirectly. As the Sun's mass has not changed and is known, the amount of potential energy changed into actual energy can be computed. The radiant energy developed by the contraction of the Solar System from a thin nebula is equal to the energy necessary to force its particles asunder and return it to a nebular condition.

After the contraction had gone on for many millions of years, the various planets were left outside of the central condensing nucleus in the way already described. When this nucleus had contracted to the size of the Earth's present orbit, it was still about 12,000 times thinner than our atmosphere at the sea level. It was therefore about as dense as the most perfect vacuum we can make with an air-pump. As it continued to shrink in size, the crowding atoms gradually gave rise to long heat-waves. In the course of ages the short light-waves were

also produced, turning the gaseous mass into a nebulous sun. It has been estimated that when it had contracted to the size of the present orbit of Mercury it gave off about one eightieth of its present radiant energy, and when the continuous contraction had reduced it to a thousand times its present size its average density became equal to that of our atmosphere at the sea level.

As the light gases around it were gradually absorbed, it slowly changed from a nebulous star into a brilliant bluish-white star, and afterward into a yellowish-white one. It is now, on the average, about one and a half times as dense as water. Its particles, therefore, fall more slowly, but produce more friction and radiance.

The Sun's contraction in size has now fallen off to about 9 inches per day — say a mile in twenty years. This is so small that it would take nearly 10,000 years to recognise the shrinkage, from the Earth, with our present instruments. The maximum of heat appears to have been passed, and the light has begun to wane and turn yellow. Some day, in the dim and distant future, spasms of chemical combination will take place in the reddening Sun. It will gradually liquefy from the centre up to the surface, and afterwards solidify from the surface down to the centre. It will then cease to contract and to give out light and heat, its potential energy having all turned into actual energy, and radiated away into space. By that time its average density will have probably increased to about twenty times that of water.

Although satellites or moons are common in the Solar System, our Moon appears to be, in some respects, an exceptional one. It is very much larger, in proportion to the Earth, than the satellites of the other planets are when compared with their primaries, and it appears to have had a different origin. Before it was born, the still molten Earth appears to have shrunk until it rotated in about four or five hours. Its equatorial parts then bulged out and became almost weightless, through the centrifugal force resulting from the rapid rotation. The pull of

the Sun on this weightless mass raised a huge tide on the Sunward side of the Earth. This gradually grew in size, so that the Earth assumed something of a pear shape. Finally the rotation became so rapid that the tidal wave was wrenched loose from the main body of the Earth and became our Moon. This tidal parentage is known as a "fission" process, and was first brought to light by Professor George Darwin.

The Earth and Moon, while still very close together, and still molten, produced huge tides in each other. The Earth-raised Moon-tides acted as a brake on the Moon and checked its rotation. At last its rotation and revolution periods became equal, so that it always turned the same face to the Earth. The Earth-tides which the Sun and Moon raised acted as a brake on the Earth itself, and at the same time quickened the forward motion of the Moon, thereby increasing its distance and period.

The Earth and Moon have now solidified, so that the tides on the Moon have ceased, and those on the Earth are almost

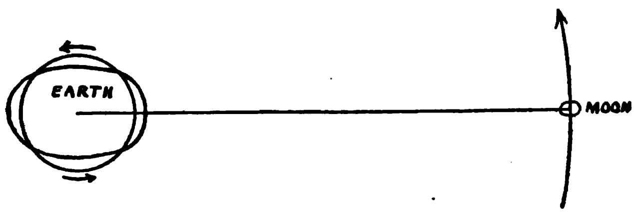


FIG. 95.—EARTH-TIDES, IF THE DAY AND MONTH WERE EQUAL

The moon's orbit would remain constant.

entirely confined to the large open bodies of water on its surface. Yet the ocean tides still continue to act as a brake to check the Earth's rotation. The effect, though small, is cumulative, and will in time lengthen the Earth's day and the Moon's "moonth" till they are both equal to about 55 of our days. The lengthening will then cease, and both bodies, though still revolving around their common centre of gravity,

will be relatively immovable, like the two ends of a dumb-bell, which always present the same face to each other.

It is not difficult to understand that the tides on each body should act as a brake and check rotation. But it is not so obvious that the Earth-tides should pull the Moon forward, and, by so doing, increase the size of its orbit and the period of its revolution. The principle is as follows:

A particle of matter at the centre of the Earth is pulled toward the Moon with *a certain force.* A particle on the side nearest the Moon is pulled with *a greater force.* And a particle on the side away from the Moon is pulled with *less force,* and is therefore (relatively) repelled. Consequently, if the Earth rotated at the same speed at which the Moon revolved, the water would bulge out, not only on the side nearest the Moon, but also on the side farthest from it (see Figure 95).

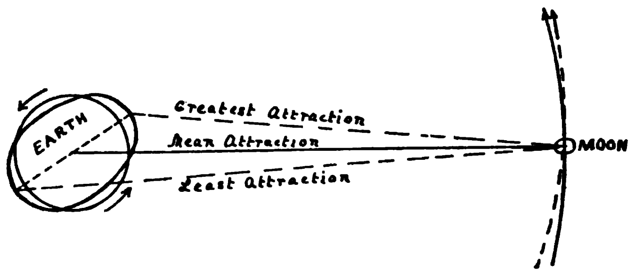


FIG. 96. — ACCELERATION OF MOON BY FORWARD PULL OF EARTH-TIDE
Moon's orbit forms a slowly opening spiral.

Owing, however, to the relative rapidity of the Earth's rotation, the tides are dragged forward by molecular friction. The tide nearest the Moon is therefore a little in front of the line joining the centres of the Earth and Moon (see Figure 96). It is the forward pull of this Earth-tide on the Moon which quickens the motion of the latter. By so doing it very slowly enlarges the Moon's orbit and lengthens its period of revolution around the centre of gravity of the Earth and Moon. The action (like that of the Earth-brake) is absolutely imperceptible,

but is, at the same time, real and cumulative. It is therefore only a question of time for great changes to be produced. And of time there is no end.[1]

By the time the Earth and Moon have reached the dumb-bell stage, the lunar tidal-friction on the Earth will come to an end, and the Moon's path will cease to be an opening spiral.

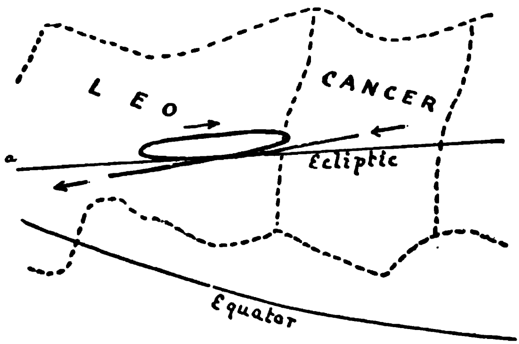


FIG. 97.—LOOP IN APPARENT PATH OF MARS

As he approaches opposition, his direct (easterly) motion amongst the stars slackens and soon ceases. He then appears to move back towards the west. After opposition this retrograde motion also slackens and ceases. His direct motion then recommences, and is kept up till the next opposition. He thus appears to make a loop every 584 days.

But until our oceans are frozen solid, the Earth's solar tides will still continue to act as a brake and check its rotation. So at last the time may come when the Earth's day will equal its year, and the same side will always be turned toward the Sun.[2]

It is rather uncertain what changes will take place after this stage has been reached. If no accident should happen, in the form of a collision with some outside body, the probability is that the satellites and planets will very slowly draw in toward their centres of revolution.[3] In this case the Moon's path will

[1] The tide which is away from the Moon tends to counteract this pull, but is too weak to overcome it altogether.

[2] Mercury and Venus appear to have already reached this stage.

[3] This theory is based upon the supposition of a resisting medium, ethereal or otherwise.

gradually get smaller, and it will, in time, reach the surface of the Earth. The two bodies will grind each other into superheated gas, which will afterward cool down and solidify. The resulting body will gradually get nearer to the Sun, and eventually grind its way into the body of its parent.[1]

By the time all the planets have returned to the Sun, and the last disturbance has subsided, one second of Eternity will

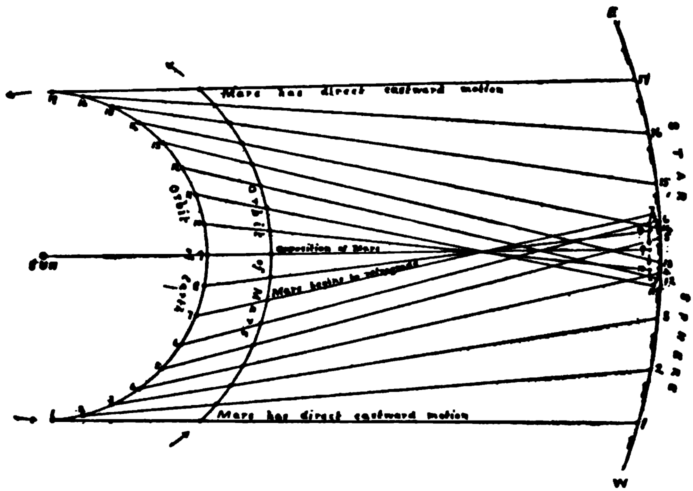


FIG. 98. — DIAGRAM SHOWING CAUSE OF LOOP IN APPARENT PATH OF MARS

The positions of Earth and Mars given at intervals of ten days. Mars appears to advance amongst the stars from 1 to 7, to retrograde from 7 to 11, and then to advance as before.

have passed away since it was in the same stage before. The Solar System will then be represented by a cold, dark, solid mass containing the same amount of matter as the original nebula. This dead hulk will drift around in the long cold starlight night (like a derelict on the broad ocean) until some similar body collides with it and turns it all into gas again. It will

[1] If this theory is correct, the matter of which our bodies are composed once formed part of what is now the Sun, and will in time return to it.

then be ready to live its life over again and give birth to another Solar System perhaps twice as large as the present one. These cycles will presumably take place an infinite number of times, the same matter being used over and over again to all eternity. This is probably true not only of the future but of the past; not only of our System but of all the systems of the Universe; not only of our Universe but of all the universes that may exist in infinite space.

Now that I am through with the Nebular Hypothesis, it may be well to remind the reader again that it is still an unproved theory. As a working hypothesis it is one of the grandest and most valuable theories ever reasoned out by the mind of man, and in its main features it is almost certainly true as far as it goes. But from the very nature of the case we are not in a position to *prove* its truth, and it is doubtful if we ever shall have anything except indirect evidence concerning it.

SUMMARY

I cannot do better than close this chapter with a summary, by Ernst Haeckel, of the most important conclusions at which science is arriving with regard to the constitution and evolution of the Great Cosmos. It is as follows:

"I. The *extent* of the Universe is infinite and unbounded; it is empty in no part, but everywhere filled with substance.

"II. The *duration* of the Universe is equally infinite and unbounded; it has no beginning and no end: it is *eternity*.

"III. Substance is everywhere and always in uninterrupted movement and transformation: nowhere is there perfect repose and rigidity; yet the infinite quantity of matter and of eternally changing force remains constant.

"IV. This universal movement of substance in space takes the form of an eternal cycle or of a periodical process of evolution.

"V. The phases of this evolution consist in a periodic change of consistency, of which the first outcome is the primary division into mass and ether, — the ergonomy of ponderable and imponderable matter.

"VI. This division is effected by a progressive condensation of matter as the formation of countless infinitesimal 'centres of condensation,' in which the inherent primitive properties of substance — feeling and inclination — are the active causes.

"VII. While minute and then larger bodies are being formed by this pyknotic process in one part of space, and the intermediate ether increases its strain, the opposite process — the destruction of cosmic bodies by collision — is taking place in another quarter.

"VIII. The immense quantity of heat which is generated in this mechanical process of the collision of swiftly moving bodies represents the *new kinetic energy* which effects the movement of the resulting nebulæ and the construction of new rotating bodies. The eternal drama begins afresh."[1]

[1] "The Riddle of the Universe," pp. 242, 243.

CHAPTER XIX

THE MESSENGERS OF HEAVEN

"In the old mythologies the Universe consisted merely of a flat World, resting on an infernal bowl, and covered by a celestial vault or canopy.

"The Gods who ruled this mundane Universe generally resided on the top of the firmamental dish-cover. There the supreme Deity had his throne, and presided over the councils of the Gods.

"As none of these Gods were omniscient or omnipresent, they had to provide themselves with angelic messengers to keep them posted as to what was going on in the World beneath, and to carry out their commands when they had come to an agreement as to what kind of left-handed justice should be meted out to the mortals below.

"These messengers of heaven were no loafers round the throne when they had a duty to perform. They could fly on the wings of the wind and outstrip the fiercest tempest.

"We now know that these angelic messengers, like the Gods they were supposed to serve, have no existence except in the imaginations of ignorant and superstitious people. But Science has revealed to us that there are messengers of heaven more swift than the wing-footed Mercury, more restless than the cloven-hoofed Satan, and more long-lived than the Father of the Gods himself."—*A. Zazel.*

VISITORS FROM AFAR

IN a former chapter I spoke about the intense loneliness of our Solar System in the midst of an immense multitude of similar systems scattered through space.

Is there, then, no physical communication between the various systems of worlds? Are they entirely and for ever cut off from one another? Are there no messengers of heaven that can serve the bidding and carry the messages of the sunny-faced Gods of ethereal space?

Yes, there are wanderers who go from star to star and from constellation to constellation. There are beings which spend almost an eternity in going to and fro in the Universe, and in flying up and down through it.

A VOYAGE OF FIVE MILLION YEARS

In order to learn something of these interstellar wanderers, let us suppose that we are back in our Chariot of Imagination, half way between our Sun and the nearest outside star. Let us also suppose that the clock has been turned back several millions of years; that we have plenty of time at our disposal; and that we have laid in a goodly supply of Job's patience.

We are surrounded, as before, by countless systems of worlds, but they are all in the remote distance. Let us move around a little, and see if our immediate neighbourhood is really as empty as it seems.

With the naked eye we might have to look for a long time before finding anything near us. But with suitable instruments we soon find that although there are no suns or large worlds in our neighbourhood there are, here and there, small fragments of hard rock floating in the otherwise empty darkness. These stones sometimes contain a large percentage of iron, and greatly resemble the meteoric stones that occasionally fall onto our Earth. They vary greatly in size, some of them being no larger than grains of sand. As there is no large world near to attract them, they are destitute of weight and simply float in empty space.

If we search long enough we may possibly come across one or two similar rock masses of considerable size, for there does not appear to be any break between these "pocket-planets" and the huge suns and worlds with which we are distantly acquainted.

In some places these airy particles of sand and gravel are thousands of miles apart, but sometimes they are so crowded together that they are only twenty or thirty miles from one another.

As these fragments of floating rock are familiar in appearance, small in size, non-aggressive in disposition, and sedentary in habit, we will not concern ourselves any more with them at present, but will stop in one place and sweep the neighbourhood with a searchlight to see if anything more important passes our way.

We may have to watch for what seems to us a big part of eternity, or our search may be successful before an earthly year has passed away.

At last our patience is rewarded by seeing something coming in our direction. It is approaching so leisurely that we have plenty of time to observe it, as it almost imperceptibly drifts by our lonely station.

With the help of suitable instruments we can see that our visitor consists of a nucleus of fragmentary solids surrounded by a thin but misty atmosphere which emits a faintly phosphorescent glow. The density of the whole mass is so small that the solid nucleus is apparently in the form of dust or ashes, with perhaps a nucleolus of larger fragments. All are practically without weight, and rest on one another as gently as so much feathery down.

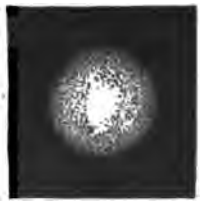


FIG. 99.—A CELESTIAL MESSENGER ON A JOURNEY

This sketch will also do for a Planetary Nebula. It should be viewed from a distance.

Our visitor is not very far away from us, as celestial distances go, and yet it appears to be almost at a standstill. Considering its size it really seems to be the quietest, laziest, deadest object we have yet come across in the Universe. With the exception of the tiny meteoric stones just mentioned, we have never seen its equal in these respects.

Let us follow this strange object in its leisurely travels through space. But be careful lest your impatience at its slowness does not bring on that kind of nervous attack which is known by western deer-hunters as the "buck-ager," for you might possibly scare the lazy-looking object, which is not as dead as it looks, and is indeed capable of travelling at a speed that would almost leave the Chariot of Imagination behind.

After keeping the new arrival in view for a million years or so, it becomes evident that its drifting motion is not due to any energy of its own, but is caused by the gravitational attraction of the far distant stars.

NEARING PORT

In the course of long and weary ages the object we are investigating gradually and imperceptibly enters the area where the attractive energy exerted by one star is greater than that of all the other stars put together. The result is that it now moves faster than before, and (like a messenger-boy nearing his destination) begins to look as though it were going somewhere.

It yields itself without a struggle to the growing influence, and imperceptibly quickens its speed with every mile it goes. As the time passes away, the now progressive messenger leaves the cold and midnight darkness of outer space, and enters the serene twilight that reigns eternal at the portals of the solar system it is visiting.

As it approaches the brilliantly glowing star and comes within the radius of its circling family of worlds, it increases still more the rapidity of its forward movement. Faster and yet faster it speeds through the gathering light. The intense cold of interstellar space has now moderated. The new arrival feels the growing warmth, and begins to unfold itself before the cheerful influence. The surrounding haze gradually melts away into a glowing gas which forms a huge luminous atmosphere around the loose and scattering nucleus.

By this time the outer members of the solar family have been safely passed. The now rushing messenger is hastening faster and yet faster toward the central star. The milestones of space fall behind as the pickets of a fence flicker when seen close at hand from an express train.

The so-called Asteroids are passed with a fearful disregard for possible collisions. Then, with still gathering intensity of ever-increasing speed, our celestial messenger flashes like a winged sword of fire through the midst of the inner planets as they circle serenely around their central sun. So great is the speed of the messenger's body that its flowing robes of luminous particles now trail behind for many millions of miles. They

FIG. 100. — A CELESTIAL MESSENGER APPROACHING A STAR

FIG. 101. — BROOK'S COMET, 1893

Lick photograph. The tail was distorted, probably by collision with a swarm of meteoric bodies.

FIG. 102. — COMET 1903 C

Lick photograph.

look, indeed, like the "wake" of a fast-moving steamer on smooth water (see Figure 100).

A CELESTIAL MESSENGER APPROACHING A STAR

The inhabitants of the minor planets tremble by night as they see what looks like a mighty two-edged sword of fire flaming in the starlit sky. Some of the more ignorant of them pray to their Gods to deliver them from the threatening monster. Others, with more self-reliance, beat their tom-toms to scare away the intruder from their neighbourhood. But, all unconscious of the commotion it has caused among the self-important microbes that cling around the circling cobble-stones, the mighty visitor sweeps majestically by on its appointed path, leading to the central star.

A HOT RECEPTION

At last, with a still more energetic rush that almost rivals the flight of the swift-winged arrows of light, the messenger of the Gods swoops down — down — down, and is lost to sight in the blasting heat and dazzling light of the solar furnaces.

To all appearances our messenger of the Gods has met with such a fiery reception that his reappearance is not to be looked for. His fall seemed to be as disastrous as that of the fabled Adversary, whom (according to Milton) —

— "the Almighty Power
Hurled headlong flaming from the ethereal sky,
With hideous ruin and combustion, down
To bottomless perdition, there to dwell
In adamantine chains and penal fire,
Who durst defy the Omnipotent to arms." [1]

One thing, however, we noticed as our celestial messenger disappeared in the solar light, and that was that he did not fall prone into the solar flames, as the traditional Adversary crashed into the molten crater of the hellish Kilauea. He seemed, in-

[1] "Paradise Lost," Book I.

deed, to fall to one side, as though he meant to skim along the surface, deliver his message, and rush out on the other side before the terrific heat could burn him up.

Knowing, however, how fearful is the heat of that stupendous globular furnace, it does not seem worth while staying to see if he has survived the ordeal. Indeed, it is uncomfortably hot even fifty millions of miles away from the blazing star. We shall have to back out of the stellar heat lest our Chariot of Imagination should catch fire, or we should lose control of the horses thereof and share the fate of the presumptuous Phaethon when he tried to drive the chariot of the Sun.

ANOTHER VOYAGE

But stay! Something has just come into sight on the other side of the star. What is it? Surely it cannot be that our messenger has safely skimmed the vast and fiery furnace, and has already reappeared on the other side, a million miles away from where he disappeared but an hour ago! It seems impossible, and yet — it is evidently the same messenger, hastening away in safety from the fiery ordeal through which he has passed.

So far from being injured by the encounter, he (like the grand hero of "Paradise Lost"), —

> "With fresh alacrity and force renewed,
> Springs upward, like a pyramid of fire,
> Into the wild expanse, and through the shock
> Of fighting elements, on all sides round
> Environed, wins his way; harder beset
> And more endanger'd than when Argo passed
> Through Bosphorus, betwixt the justling rocks;
> Or when Ulysses on the larboard shunn'd
> Charybdis, and by the other whirlpool steered."[1]

Strange to relate, our fast-retreating messenger has been beaten in the race by his flowing garments. These, instead of trailing behind in the solar furnaces, are now extended in front

[1] "Paradise Lost," Book II.

of him for many a million miles, as though anxious to get back into the outer cold and darkness.

Let us turn our chariot and trace him as he recedes from the star. We have not followed him very far before we find that his speed begins to slacken, and that he is apparently gathering in his garments. By the time that we are once more in the dark, outside the stellar system, he is again nothing but a round mass of faintly glowing haze, drifting idly through the midnight sky.

So he keeps on, century after century, drifting — drifting — drifting, like a ship becalmed by night in the solitude of a tropic sea.

On our little Earth — and perhaps on millions of similar worlds scattered through space — continents appear above the seas and are pounded to pieces by the waves. New and higher forms of life develop, and give way in their turn to still more specialised species. The huge reptiles of the Earth's Oolite yield to the warm-blooded mammalia of the Tertiary period. The four-footed tree-dwellers develop ape-like peculiarities. The sharpest of the four-handed apes desert the trees and adapt themselves once more to live on the ground. *Pithecanthropus erectus* develops into *Palæolithic Man*. *Neolithic Man* is driven into the mountains by those who have chariots of iron. Nations, empires, and races come into existence, flourish for a time, and pass away, like ephemeric clouds in a summer sky. The *chattel-slave* and his *master* develop into the *serf* and his *lord*. The *wage-slave* and his "*boss*" become *economic equals* in the *Industrial Commonwealth*. And still this hazy mass is drifting — drifting — drifting, through ethereal realms of star-lit space.

A million times our World goes around its Sun, and still our lazy messenger is imperceptibly drifting through endless night. For two — three — four — five millions of Earth-timed years he drifts — drifts — drifts along, and then, coming once more under the influence of a star, he repeats his former rush, but around another sun. Again he goes into the outer darkness,

drifts through almost endless years, and again he rushes around another star. And so he spends what seems to us almost an eternity of time.

A CAPTIVE MESSENGER

Sometimes the influences which surround a star cause him to close his orbit and circle around and around the same star in a long narrow orbit. But some time or other the attraction of a planet turns him out of his closed orbit, and he once more goes off and drifts — drifts — drifts through endless space.

COMETS

It is hardly necessary to state that our Messenger of the Gods is nothing more or less than what is known to us as a *comet.* Such bodies exist throughout the Universe in hundreds of millions. Until recently we were entirely in the dark as to their composition, origin, and movements. Their nuclei, it is true, were known to submit to the law of gravitation, but hardly a guess could be made as to the nature of the repulsive force which produces and dominates over their tails. Even yet we have much to learn concerning comets generally. But some of the main facts have been ascertained, and a reasonable theory has been formed which throws a good deal of light upon them.

The probability is that they are huge collections of loose meteoric dust and gravel, with large quantities of hydrocarbons and free hydrogen. All this loose material has been ejected into space from solar or planetary volcanoes. In the intense cold of outer space (which is at least 230° below zero on the Fahrenheit scale, and may possibly be — 461°), the hydrogen and hydrocarbons naturally cling evenly around the solider material.

On approaching a star, the radiant energy from the central sun causes them to spread in all directions around the scattering nucleus. They thus form the cloudy haze of which all

telescopic comets consist. When still nearer, the spreading particles in front are further dissipated by the heat. At last they are so small that the radiant energy of the sun overcomes their gravity, and violently repels them into outer space. There, lighted up by the sun, and glowing with a soft electric light of their own, they form the tremendous hollow luminous

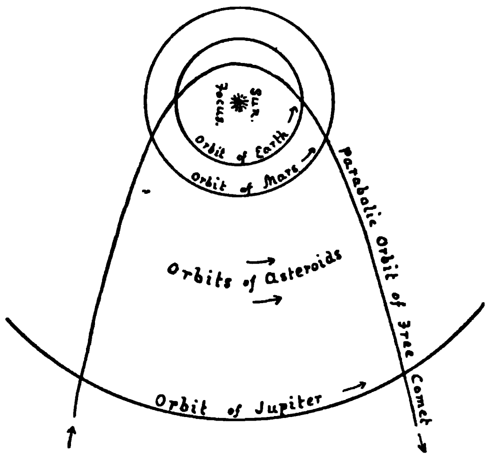


Fig. 103. — Parabolic Orbit of a Free Comet

It is practically an ellipse with the two foci at an infinite distance from each other. Hence the orbit is closed at only one end.

trumpet-shaped appendage known as the tail of the comet. The shape of the tail, and its direction in space, depend on the strength of the repelling force, and that varies with the size of the particles composing the tail. Sometimes there are several tails, extending in different directions, or, rather, in different curves. There appear to be three different types of tail, differing in direction, shape, and material. The straightest ones are probably composed of hydrogen. They are repelled with the greatest force, and therefore extend almost directly away from the Sun. The next are more curved, and are supposed to con-

sist of varying hydrocarbons. They are repelled with about one quarter the force of the hydrogen tail. The third type is still more curved, and probably consists of chlorine and iron. The repulsion is only about one sixteenth that of the hydrogen tail. All of these tails are hollow cones, of which only the sides are generally visible.

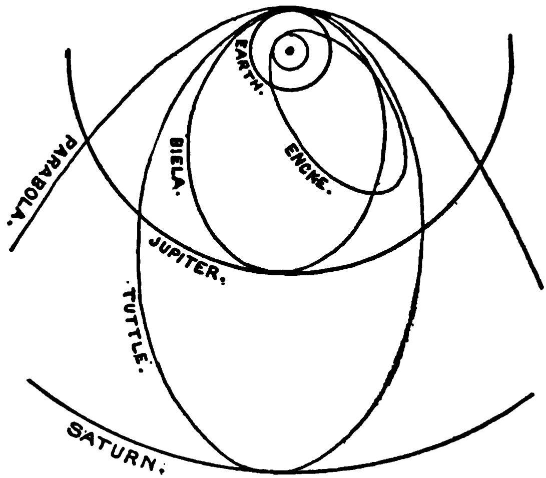


Fig. 104.—Elliptical Orbits of Captive Comets

As fresh particles are being sent out into each tail all the time, it naturally follows that after the head of the comet has begun to recede from the Sun its newly formed tails stretch out in front of it. In the meantime the old ones have been driven off and dispersed.

As before stated, the main body of a comet obeys the same laws that control the motions of all the heavenly bodies. The luminous gas of which a comet is largely composed is so thin and transparent when within the Solar System that the faintest stars can be seen through millions of miles of its substance. The whole comet is so light in weight that it can sweep by the

FIG. 106. — DONATI'S COMET, 1858

By Bond. (*From Comstock's "Text-book of Astronomy," published by Messrs. D. Appleton & Co.*)

FIG. 107. — COMET RORDAME, 1893

By Hussey, at Lick Observatory.

planet Saturn without disturbing the motions of his numerous family of moons, while these same moons, small as they are, are able to deflect it from its original path if it should happen to pass near them.

PERIODIC COMETS

"Amid the radiant orbs
That more than deck, that animate the sky,
The life-infusing suns of other worlds;
Lo! from the dread immensity of space,
Returning with accelerated course,
The rushing comet to the Sun descends;
And as he sinks below the shading Earth,
With awful train projected o'er the heavens,
The guilty nations tremble." — *Thomson*, "The Seasons" — Summer.

Some of the comets that move in closed orbits around our Sun have had their elliptical paths traced out by the astronomers. They are not confined to the Ecliptic, like the planets, but are inclined at all angles to it. Their regular coming can be anticipated, though their movements are never to be depended on, owing to the ease with which they are turned out of their course by the planets they happen to come near.

FIG. 105. — TAIL OF A COMET NEAR PERIHELION

Several of the periodical comets have paths extending to the orbit of Jupiter. Others go away as far as Saturn and Uranus. This is one of the peculiarities which gave rise to the theory that they were originally thrown out from those giant planets by tremendous volcanic eruptions, like those which are constantly taking place on the apparent surface of our Sun. This theory is now generally abandoned, on account of the tremendous force necessary to overcome the gravitation of such huge planets.

They are now believed to have been captured by the planets

to which they are related. Tempel's comet, which is connected with the Leonid meteors — and which goes away as far as the orbit of Uranus — has had its orbit traced back to the year 126 A. D. At that date the two bodies were very near together, and the planet appears to have drawn it (and the Leonids accompanying it), out of the original parabolic orbit into an elliptical orbit having a period of about 33 years. Such changes of orbit appear to be not uncommon among comets.

The spectra of comets contain three bright hydrocarbon bands well defined at the red end. There are also several bright iron lines, and one due to manganese. When a comet is near the Sun, the bright sodium lines are sometimes seen. In addition to this emission or radiation spectrum, there is generally a faint absorption spectrum visible, with dark lines.

METEORS

Another peculiarity of these erratic wanderers is that some of them are intimately connected with meteor showers. When

FIG. 108. — A METEOR BURSTING IN THE ATMOSPHERE
Seen through a telescope.

our Earth passes *through the path* of one of these captive comets, vast multitudes of so-called "shooting-stars" enter our atmosphere and burn up with the heat generated by atmospheric friction. Where fragments of meteors happen to reach the

surface of the Earth, they are found to consist of volcanic substances like those thrown out by earthly volcanoes. Many of them consist of irregular fragments cemented together. Some contain considerable iron, and carbon has been found in a few. Even mineral veins have been found in them.

Our Earth has now lost a great part of its volcanic activity, yet the eruption of Krakatoa, a few years ago, was almost powerful enough to cast its *débris* clear of the planet's attraction.

Supposing such a thing to take place, the cast-out masses, both gaseous and solid, would naturally turn toward the Sun, rush around that mighty globe, and, if not consumed by its heat, return to the place where the Earth was when they were ejected. Not finding the planet where it had been, the stream of meteoric matter would naturally turn to the Sun again, and continue in the same orbit until its Earth-derived particles were all picked up again by the Earth or Moon.

If these comets and clouds of meteoric dust should originate in the way described, it follows that moderate-sized worlds of other systems must be equally capable of casting out similar masses of cometary gas and meteoric solids. This would explain the great abundance of comets and meteoric streams in our own system.

There is some evidence that both comets and meteoric streams gradually waste away when travelling through solar systems. At each approach to a star, a comet appears to lose the repelled matter which forms its dissipated tail or tails. After a certain number of perihelia the supply of hydrogen and hydrocarbons fails. Short-period comets are therefore generally tailless. A comet has also been known to split up into two separate bodies which gradually drifted apart. In some cometary orbits there appear to be several comets, all moving in the same path, but at long distances apart. Sometimes the solid bodies forming the nucleus of a comet appear to spread out along its orbit until the comet disappears and nothing remains but a long trail of invisible meteoric matter. Meteoric streams also waste away

to some extent, owing to the capture or deflection of fragments by passing planets. The captured fragments of course form the meteors and "shooting-stars" with which we are so familiar on Planet Number Three.

It seems, therefore, that, long-lived as the comets are, they too have a limit in duration. They are not "built for eternity," but are as ephemeral as the suns and worlds among which they wander. But the loss is evidently made up by the constant formation of fresh comets and meteoric streams in various parts of the Universe.

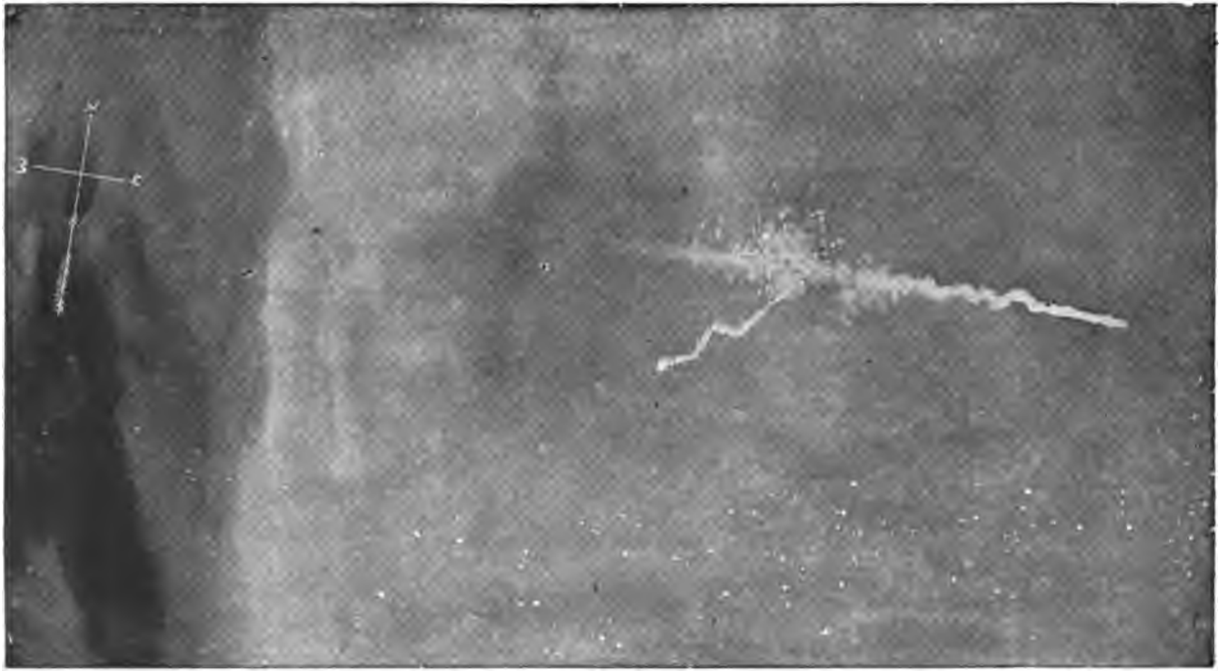


FIG. 109. — THE CALIFORNIA METEOR OF JULY 27, 1894
Drawing by Chauncey St. John.

CHAPTER XX

LARGE AND SMALL WORLDS

"There are worlds so vast that beside them our Earth would seem but a toy. There are worlds so small that they might serve as marbles for our children to play with." — *A. Zazel.*

IT has been already shown that both suns and worlds vary enormously in size and in the amount of matter they contain. But it is very hard to realise how vast these differences are. In our own System, while some planets are immensely larger than our Earth, others are too small to be visible with any telescope unless they happen to be massed together in millions, as in the rings of Saturn. It may be well to illustrate some of these differences, paying special attention to the Third Planet, the largest planet, and the Sun.

MICROSCOPIC WORLDS

There are "planets" going around the Sun which are so small that if we had them in our hands we could not see them without a microscope. They are commonly called meteoric bodies, yet they really and truly are worlds like ours, revolving in orbits more or less similar to ours. They are subject to the same laws, and may have had a separate existence as long as the Earth on which we live.

At the same time there are planets, going around the same Sun, so vast that our Earth would appear utterly insignificant beside them.

OUR INSIGNIFICANT EARTH

Jupiter, the largest planet in our system, weighs 300 times as much as our Earth. Not having yet cooled down so much as the Earth, it is more than 1,200 times as large.

Our Sun weighs 330,000 times as much as the Earth, and for the same reason is 1,250,000 times as large.

Two or three illustrations may make these comparisons plainer.

If our Earth be represented by a ball one inch in diameter, Jupiter's *weight* will be represented by a globe, of the same

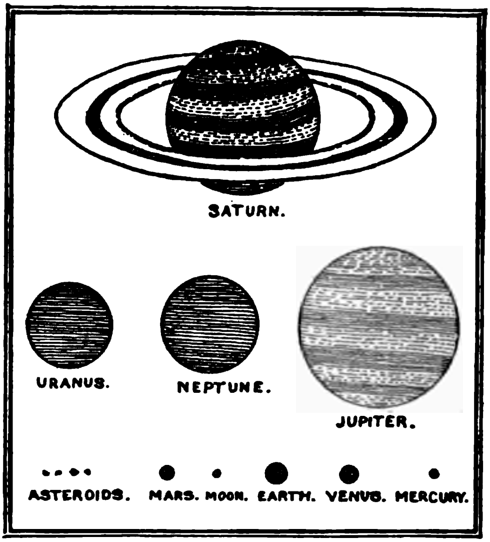


FIG. 110.—RELATIVE SIZES OF PLANETS

density, 4.2 inches thick, and that of the Sun by a globe 5 feet 9 inches across.

With the same one-inch ball for our Earth, Jupiter's *size* will be represented by a globe 11 inches thick, and that of the Sun by a globe 9 feet across.

If we were to place in a straight line enough of these one-inch globes to represent the *weight* of Jupiter, they would extend 25 feet, while if we were to put in a line enough to represent the *size* of Jupiter, they would reach 100 feet.

To represent the Sun's *weight* in the same way, we should

require a string of them more than *five miles* long. And for its *size, nearly twenty miles* of them.

The difference between the mass of the Sun and that of the Earth may also be illustrated in this way. A weight dropped from a height on our Earth falls a little over 16 feet in the first second. But on the Sun it would fall 452 feet in the same interval of time. An object which, on account of the Earth's attraction, here weighs *one pound,* if removed to the apparent surface of our Sun, and weighed by a spring balance, would be found to have increased its weight to 28 *pounds* on account of the greater mass and attraction of the Sun.

Fig. 111. — Relative Sizes of Sun, Jupiter, and Earth

These two illustrations do not really do justice to the difference between the mass of the Earth and that of the Sun. For the Sun's centre of attraction is 108 times as far from the object on its surface as in the case of the Earth.

To get over this difficulty, let us imagine the Sun to be compressed until it is the same size as the Earth, without diminishing its mass. It will then be 330,000 times as dense as the Earth. The object which, on the Earth, weighed a pound, will now, when removed to this compressed Sun, be found to weigh 165 American tons. And a weight dropped from a height will fall 1,000 miles in the first second.[1]

[1] This compressed illustration is of course impossible, but it will serve to show the immense difference in the quantity of material contained in the Earth and Sun.

All the other planets in our System, taken together, weigh about 450 times as much as our Earth, yet the Sun outweighs them all 745 times. If all the planets be represented by a heap of boulders weighing 450 pounds, a little one-pound pebble will stand for the Earth. And on the same scale the Sun will be represented by a mighty rock weighing about 170 American tons.

Our Moon is 2,162 miles in diameter, and looks, from here, as though it were the same size as the Sun, yet the latter exceeds it in bulk more than 60,000,000 times, and in weight 27,000,000 times.

FIG. 112. — RELATIVE SIZES OF THE FIRST FOUR ASTEROIDS AND THE EARTH'S SATELLITE. BY BARNARD

The black circle represents the Moon, and the white ones the Asteroids.

Go out on an unusually clear night, when the Moon is below the horizon. Notice what a multitude of stars can be seen by the naked eye alone. Imagine every star visible to be 600 times as large as our Earth. Then all of them rolled together into one vast globe would not be as large as the Sun.

Yet our Sun is comparatively a small star. Canopus, one of the bright stars in the southern hemisphere, gives out many thousands of times as much light. If its lustre is equal to that of the Sun, it must be many thousands of times larger.

OUR MIGHTY GLOBE

We thus see that our planet is a very insignificant world compared with some of the other heavenly bodies. Yet it contains what seems to us to be a considerable amount of material.

Let us suppose the Earth to be drawn out into a long square column a mile thick each way. This column would reach from

the Sun to a distance 93 times as great as that of the planet Neptune.

Let us suppose that this long column was put on suitable flat-cars and started off at 50 miles an hour. Then suppose we saw it coming, and decided not to cross the track till it had passed by. We should have to wait 590,000 years before the line would be clear.

A signal-light flashed from one end of this train, at the usual speed of 186,000 miles in a second of time, would not be seen at the other end for sixteen days.

If our Earth could be crushed under foot till it was flattened out, so as to be only a mile thick, it would form a round flat disc, 565,000 miles across, — considerably larger than the Moon's orbit.

So that if our Earth is of but slight importance in the Universe, it must be admitted that it is a considerable size when looked at from a human standpoint.

THE CRASH OF WORLDS

Theoretically, every atom of matter in the Universe influences every other atom of matter in the Universe. And practically it influences all within x millions of miles.

Yet as a rule the myriads of suns and worlds do not interfere with one another. They keep on in the even tenor of their way from century to century. For many ten thousands of millenniums they keep out of one another's way.

Still, accidents will happen even among solar systems. There appear to be times when suns and planets come into collision, when even worlds suffer shipwreck.

Some of the stellar systems are drifting along at the rate of *two hundred miles in one second* of time. Therefore such catastrophes are liable to give rise to a considerable amount of light and heat.

Whenever you see what is miscalled a ***shooting-star*** dart across the sky and disappear, you witness the destruction of a "pocket-planet" which *may be* as old as our Earth.

Whenever you see the fiery rush of a *meteor*, and hear its distant crash, you may know that another little world has met its doom and ceased to have an independent existence.

Whenever a star suddenly increases in brilliancy, and for a time gives out many thousands of times its former light, you may feel tolerably certain that mighty suns have crashed into mutual destruction.

Yet nothing is really destroyed. The "shooting-star" still exists as vapour or dust in our atmosphere; the meteor settles down to form part of our Earth; the crashing suns, though turned to flaming gas, unite and begin once more the same endless cycle of evolution and devolution. There is no end, nor was there yet beginning.

STARS ARE SOLITARY

"His soul was like a star, and dwelt apart."

Many people still have the old idea that the stars, although a long way from us, are comparatively close to one another. This is not at all correct, in spite of the fact that in thousands of cases two, three, or more stars form one system.

Some of the *star-clusters* appear to be *democratic* systems composed of vast numbers of comparatively small suns revolving around their common centres of gravity. Thus the cluster Omega Centauri consists of more than 6,000 stars, of which at least 125 are variables (see Figure 94). In cases like this it is not likely that the individual suns have planets revolving around them, or, at least, not habitable ones.

But leaving these multiple systems out of consideration, it may be said that each star is, with the exception of its subject worlds, solitary in space. If we could take our stand at a comfortable distance from any one of these *sovereign* stars, we should imagine the system to be in the centre of a huge void, surrounded, at an enormous distance, by a hollow sphere of crowded stars. Or, in other words, the heavens would look about the same as they do from our Solar System. In the case

of a neighbouring star, only an expert could detect any changes in the constellations.

When we see two stars which appear to be near to each other, we must remember that in many cases one star is two, ten, twenty, or a hundred times as far from us as the other one. It may even be that the brighter one is the most distant.

On this account the apparent brightness of a star as seen from our Earth is a very unreliable guide as to its distance or size. As a matter of fact, no two stars are alike in actual size, brilliancy, colour, or any other peculiarity.

STARS ARE MIGHTY SUNS

"The stars of heaven fell to the ground, as green figs fall when the tree is shaken by a mighty wind." — *Rev.* vi, 15.

Then we must remember that every one of these sovereign stars is a SUN *more or less like our Sun.* Every one seen is at least something like 1,000,000 times as large as our Earth. The smallest visible is worthy of the name of SUN; is large enough, powerful enough, hot enough, and bright enough, to hold sway over worlds as beautiful as Venus, as fiery as Mars, as vast as Jupiter, as magnificent as Saturn, as distant as Neptune, and as populous as the little Earth on which we live.

Every star visible is blazing with a light peculiar to itself, different from the light of any other. In the vast majority of cases this light is intense enough to make the Columbian search-light look black by comparison.

Each of these suns is throbbing with quaking blasts of fervent heat that would make the molten interior of a Bessemer converter seem cold by comparison. The eruptions of Mont Pélée, fearful as they seemed to us, were but the sputterings of a bunch of Fourth of July fire-crackers when compared with the awful cannonading which goes on, every day in the year, all around the average star.

So intense is the heat of our own central star that if the Earth were to be checked in its career and left to fall toward

the Sun, it would never reach the photosphere in a solid state, but would be turned into flaming gas, and driven off again, like a hailstone falling toward a mass of molten steel. Sir John Herschel showed that if an icicle 45 miles in diameter could be driven endways into the Sun with the velocity of light (186,000 miles per second), it would be melted off as quickly as it advanced. Some of the larger stars could dispose of an icicle more than 100 miles in diameter.

Every star is continuously roaring and throbbing with ear-rending detonations and world-jarring convulsions that are greater, in one short hour, than all our thunder and lightning, earthquakes and volcanic eruptions, for millions of years gone by. Every one is dragging its attendant family of worlds through the wilderness of space at a speed that the mind of man cannot realise, it is so tremendous.

A TINY GLOBE

"The Earth is my foot-stool." — (*The Later*) *Isaiah*, lxvi, 1.

In all this splendour of molten orbs, our Earth, fortunately for us, has no part. Silent, dark, and invisible (except to three or four of its nearest companions), *it is of no measurable importance in the economy of Nature.* So far as other worlds are concerned, its existence is no benefit, its disappearance would cause no anxiety, its destruction would be no loss, its absence would give no trouble.

Yet, fastened to the radiant skirts of the glorious Sun by invisible yet unbreakable bonds, it has been dragged for many millions of years, through the wilds of space, at a speed inconceivably great. Small though it is, it is teeming with life of every kind. It contains almost boundless oceans and continents. It has mountains and valleys, rivers and lakes, islands and seas, beautiful beyond the power of words to describe. It has a history extending back millions upon millions of years. It has a future almost without end.

HUMAN ACHIEVEMENTS

So far I have considered only the smallness and insignificance of man. But there is another side to the question. A thing may be small and yet wonderful. The ancestors of man were all Earth-born. He himself is but the creature of a day, and has all his life been on one insignificant planet with no prospect of ever leaving it. Yet, considering his situation, he has done some wonderful things. Leaving out of consideration all his earthly achievements, he has eaten of the fruit of the Tree of Celestial Knowledge to a far greater extent than might have been expected. Cooped up in his invisible cage, he has contemplated the visible parts of the Universe to such good effect that he has solved many of its mysteries. Not satisfied with the eyes provided by Nature, he has constructed artificial instruments which increase their light-grasping power more than 40,000 times. With their help he is measuring the depths of space, analysing the stars as though they were in his laboratory, weighing suns and worlds in a balance, and photographing celestial objects that are invisible even with his instruments. He traces the wanderings of the planets both in the remote past and the distant future. He is finding out the life-history of a sun from its cradle to its grave. He watches the stars so closely that millions of them are unable to move without his knowledge. The infinitely great and the infinitely small are alike compelled to submit to his scrutiny. Slowly but surely he is compelling Nature to give up her innermost secrets. He is gradually solving the mystic riddle of the Universe.

These be no light achievements for man to have even partially accomplished. The Gods of Greece and Rome never attempted such tasks. Odin and Thor never dreamed of such vast undertakings. The labours of Heracles and feats of Shemishon cannot be mentioned on the same page without provoking a smile. The actual achievements of man surpass those fabulously attributed to the Gods and heroes of antiquity.

TWO STANDPOINTS

"The Hebrews looked upon themselves as Yahveh's Peculiar People, which they probably were.

"The Chinese regard the 'Celestial Empire' as the most important part of the World, which it is — to them.

"Every little Boston is thought, by its own people, to be the 'Hub of the Universe,' which it possibly may be — to those that dwell therein.

"But a Citizen of the Great Cosmos — though compelled to view all things from his own physical standpoint — can see them also from a spiritual standpoint which is Universal and Eternal." — *A. Zazel.*

To the ancients, the World was visible only from a local standpoint, with the eyes of an ephemeron. From their position it appeared to be *vast* beyond comparison, *fixed* beyond the possibility of removal, *changeless* as the decrees of destiny, *eternal* as time itself.

We, who have eaten of the fruit of the Tree of Knowledge, have acquired the power of observing the Earth from both a local and a universal standpoint. We have learned of its *insignificance,* yet we better comprehend its *vastness.* We know that it is *ever on the wing,* yet we understand the *undeviating fixity* of the paths in which it travels. We watch its lands and seas *come and go like drifting clouds,* yet we are aware of the *changelessness* of the laws to which those changes are due. We know it as a *transient bubble* on the River of Eternity, yet we have discovered *a history that staggers even the imagination* itself, and can foresee *a future that shall rival its past.*

CHAPTER XXI

IGNEOUS FORCES ON THE MOON AND ELSEWHERE

"He scarce had ceased, when the superior fiend
Was moving toward the shore: his ponderous shield
Ethereal temper, massy, large, and round,
Behind him cast; the broad circumference
Hung on his shoulders like the Moon, whose orb
Through optic glass the Tuscan artist views
At evening from the top of Fesolé,
Or in Val d' Arno, to descry new lands,
Rivers, or mountains, in her spotty globe."
— *Milton*, "Paradise Lost," Bk. I.

BY this time we should have a very fair idea of the construction, dimensions, distances, and histories of the various celestial mansions which compose the visible part of the Grand Temple of the Universe. It is now time to turn nearer home and find what there is to be seen and learned of the satellite which is such a faithful attendant on the Third Planet of the Solar System.

Some details have already been given about our Moon, but little has been said concerning its present appearance and condition, or about the changes that have taken place on it since it left the embrace of its earthly parent.[1]

The history of the Moon, like the histories of its ancestors — the Earth, the Solar System, and the Universe — is not recorded in books that were written by eye-witnesses. It has to be obtained by carefully observing its present appearance and condition, and then by reasoning as to the way in which natural laws (known and unknown) can have brought about

[1] Since the Moon owes its separate existence to the gravitational attraction of the Sun on the body of the Earth, it shares with many of the heroes of antiquity the honour (?) of having a heavenly father and an earthly mother.

that appearance and condition. The most that we can reasonably hope for, under these circumstances, is to get a fairly accurate idea of the main sequence of events without laying too much stress on minor details. Indeed we must not be surprised if we find that recognised authorities sometimes differ with regard to the course of events, as well as to the relative importance of the different agencies that have been at work on it. Past experience has shown that incorrect theories will sooner or later be found out, and replaced by others that are nearer the truth.

LUNAR FEATURES

If we examine the Moon with the unaided eye, when our side of it is fully illuminated by the Sun, we can see very little as to its condition except that it appears to be a tolerably bright round disc with some *irregular dark patches* on it. Each of these dark patches remains permanently in about the same part of the disc, and has been there since history began. It is therefore evident that the Moon always turns the same side to us. The only considerable change is in the direction from which it is illuminated by the Sun as it revolves around the circling Earth.

With the help of an opera-glass (also used at full moon), these lunar patches become very much plainer, and appear to have a somewhat circular outline. There also comes into sight a star-like series of *bright radiating streaks*, having their centre near the south of the visible disc. These two peculiarities together give the full moon a strong resemblance to a peeled orange that has been badly bruised.[1]

[1] If two photographs of the Moon are taken from rather different standpoints, and then combined so as to be used in the stereoscope, this resemblance to a bruised orange becomes quite startling. Thus viewed, the Moon loses the flat disc-like appearance due to its immense distance, and stands out as a solid sphere just as it would appear to a giant whose eyes were thousands of miles apart. The same principle has also been applied to planets and comets, so as to show them as they really are, standing out solidly between us and the more distant background of stars. Efforts are now being made to get similar stereoscopic pictures of the stars, by coupling photographs taken at intervals of many years.

FIG. 113. — FULL MOON SHOWING RADIATING STREAKS

With a small telescope the whole surface is seen to consist of solid land like that of our continents. The Moon is therefore a solid sphere (or spheroid) like our Earth, but without any oceans or seas. The dark patches are now recognised to be *tolerably level plains* of a darker material than the rest of the surface. Some of these plains are more or less surrounded by *mountain chains*, or lesser elevations.

The telescope also brings into view a large number of smaller and more regular circles scattered on all parts of the visible surface. Those, however, which are near the edge of the disc are distorted into ellipses by perspective. The largest of these rings are easily seen to consist of a circular embankment or rampart surrounding a saucer-like depression in the centre of which there is often an irregular conical elevation.

When the Sun shines obliquely on these circular ramparts, their shadows are seen extended on the plains beyond, as well as on the floor of the interior. Where they are numerous the scene reminds one of a plaster-of-paris surface that has been filled with bubble-holes by means of citrate of magnesia. When such a surface is illuminated from one side by a powerful electric light, it makes an almost perfect representation of some parts of the lunar disc.

Those who are acquainted with volcanic districts on our Earth will have no difficulty in recognising these hollow circular objects as *volcanic craters* with or without central lava cones.

These lunar craters are extremely numerous and vary greatly in size. The largest are considerably over one hundred miles across, and below this all sizes are represented down to invisibility, the smallest seen being less than a mile across.

On and near the dark plains these craters are tolerably plentiful, but toward the southern part of the Moon's disc they are so astonishingly numerous that they crowd together and overlap one another. The large ones are often filled with, and surrounded by, swarms of little ones, which even perch on the summits and slopes of their ramparts.

Several of the larger craters form centres for bright star-like *radiating streaks* extending along the surface for hundreds of miles. The most extensive set of these has already been mentioned as giving the full moon the appearance of a peeled orange. Its longest streak can be traced for over 2,000 miles.

With a powerful telescope long narrow *cracks* are also visible on the Moon's surface, as well as *crust foldings* and all kinds of small irregularities which need not be here described. They are beautifully pictured in Nasmyth and Carpenter's splendid but expensive work entitled "The Moon."

IGNEOUS FORCES

Now it is evident that most, if not all, of the lunar features just mentioned are of exclusively igneous or volcanic origin.[1] There is no single feature or peculiarity which can with certainty be ascribed to either air or water. Oceans, seas, lakes, marshes, rivers, planes of denudation, snow-patches, ice-sheets, clouds, mists, and such-like aqueous features and phenomena, are conspicuous by their total absence.

On our Earth the various *aqueous agencies* have for millions of years waged an unceasing conflict with the *igneous agencies*, and have now almost won the fight. But on the Moon the igneous forces have had all the field to themselves, and have had to deal with a force of gravitation only one sixth as great as that on our Earth. We therefore find that all the lunar features are such as would be produced by volcanic forces working under peculiarly favourable conditions. When compared with similar volcanic features here they are seen to be on a vastly greater scale, differently proportioned, and more perfectly preserved.

Before dealing further with the condition, peculiarities, origin, and development of these lunar features, it may be well to say a few words about the various ways in which volcanic forces are likely to act under widely different conditions. We

[1] The word "volcanic" is here used in its widest sense.

shall then be better able to understand the unfamiliar shapes, sizes, and other peculiarities of the lunar relics of igneous action.

HOW A MOLTEN WORLD SOLIDIFIES

The cooling off of a luminous gaseous sun or planet, first into a liquid and then into a solid state, is an exceedingly protracted process. An appreciable part of it has never been witnessed by ephemeral man. This being the case, it must be borne in mind that the following account is almost entirely theoretical. *No one can prove its truth,* though the greater part of it is supported by many forms of indirect evidence. The most that can be said for it is that it is exceedingly probable.

After a gaseous sun-like world has cooled off sufficiently to allow its most combustible elements to burn themselves into chemical compounds, it still continues to cool off by radiation into space. So in time the bulk of its material leaves the gaseous state and forms a spherical white-hot molten globe. This is extremely dense and compressed at the centre, where the heavier elements and compounds naturally tend, and comparatively thin and "watery" near the surface, where the pressure is small. When the molten globe is of any considerable size it is surrounded by an atmosphere composed of those gases which liquefy only at a low temperature.

If the world under consideration is only a subordinate centre of condensation, it still continues to revolve around the main centre, as in its gaseous youth. Its rotation not only continues, but (if not counteracted by tidal action) increases in rapidity as it cools and shrinks. And any tides that may have been previously produced in it by large neighbouring bodies will still continue to affect it.

In time the radiation of heat into space will chill, and eventually freeze, the surface of the molten world. The time occupied in solidifying will depend on the mass of the cooling world and on the resulting density of its atmosphere.

The solid outside crust will gradually get thicker, but, if

neighbouring worlds cause any considerable tides beneath, it will be liable to be fractured as soon as it loses some of its flexibility. The cooling and freezing processes, however, go on at the surface without interruption, though considerably hindered by the more or less violent physical and chemical reactions below.

At last a tolerably solid crust is formed, covering the entire world to a considerable depth. This crust is all the time encroaching on the molten nucleus inside it, and will eventually replace it to the very centre.

But before that can take place there will be a terrible struggle for supremacy between the cooling and crushing shell, and the crushed and overheated nucleus.

For the laws of cooling and contraction are such that just before a liquid turns to a solid it swells out and occupies more room than it did before, and that after it has solidified it shrinks as it continues to cool off.[1]

Owing to these peculiarities the solid outside crust at first contracts faster than the nucleus inside it. The strain produced by this cause (assisted by the presence of confined gases) is tremendous beyond conception, and appalling in its world-wide effects. When at its greatest intensity it causes the world to throb and quiver from centre to circumference. The crust fractures and gapes from pole to pole. Near the centres of force the surface-blocks jump like the lid of a pan full of boiling water. The molten rock and its confined gases (which consist partly of the vapour of water) force their way through the cracks and gaping fissures. Where their escape is strongly opposed, they issue in explosive fountains of fiery solids, liquids, and gases, and bombard the heavens with an incessant and ear-rending cannonading that defies description. If an eyewitness could view the stormy scene from a safe distance, he might think that the throes of Ragnarok were at their height.

[1] The freezing of water and solidification of type-metal sufficiently illustrate the former peculiarity, and the cooling of almost any solid substance exemplifies the latter.

FIG. 114. — THE MOON, AT FIRST AND LAST QUARTER
Photographed at Lick Observatory.

And in fact he would not be far wrong, for the old Norsemen probably got the germ of that grand conception from the world-rocking convulsions of the Icelandic volcanoes.

In the course of time the solidifying process gets nearer the centre of the world. The igneous forces are therefore hampered by the increasing weight of the solid crust above. The molten nucleus now contracts faster than the solid crust, and the latter crumples and folds as it settles down on the outside of it. The strains produced by both contraction and expansion vary in direction and intensity, and the surface phenomena vary accordingly. The igneous manifestations in time become less violent, and the conflict gradually dies away into feeble and intermittent spasms, which at last entirely cease.

The natural features resulting from the above conflict vary according to the intensity of gravitation, the density of the atmosphere, the amount of water above and below the surface, and such like peculiarities, and these, in their turn, depend largely on the size of the cooling sphere.

TIME OCCUPIED IN SOLIDIFYING

On a little world, like our Moon, for example, the force of gravitation is small. Consequently the gases and vapours appear to leave the planet as they are liberated. It is therefore exposed to the intense cold of outer space, and, as its surface is large when compared with its mass, it cools off in a comparatively short time.

On a somewhat larger world, like the Earth or Venus, gravitation is more powerful, and retains all the gases except the very lightest. It is therefore surrounded by a dense, foul, and cloudy atmosphere, which retards and lengthens the cooling process. But, as soon as the surface temperature is low enough the aqueous vapour in this atmosphere turns to liquid drops and rains down on to the solid surface. At first this surface is too hot to retain the water, and it is driven off again in the form of steam. But after a time it collects into rivers of hot

water and flows into any depressions there may be in the crust. There it forms oceans, seas, and lakes, of more or less saline water. This, by its alternate evaporation and condensation, produces on the dry land all the well-known phenomena of aqueous denudation.

On a still larger world, like Saturn or Jupiter, the process is still more hampered and prolonged by the intensity of gravitation and by the extent and density of the cloud-packed atmosphere.[1]

In the case of huge bodies like our Sun, and of still larger ones like Canopus and Rigel, the time taken to cool off (first to a liquid, and then to a solid state) is so enormous that it is beyond the comprehension of ephemeral beings. Reason may be able to estimate the period in years, but even the imagination fails to grasp and realise its vastness.

COMPARATIVE EFFECTS OF IGNEOUS FORCES

When this conflict was at its height on our Earth, the central attraction of gravitation was (as now) considerable when compared with that of the Moon, and there was a dense acrid atmosphere all around, which at first contained all the water now in the oceans. These features would act as a check on the igneous forces, prolong their action, and make their permanent records less conspicuous. Yet geology shows that some tremendous results were produced even when the conflict was dying away.

Leaving the more ancient and important effects out of consideration, the crater of Haleakala, which has an area of 16 square miles, is an awe-inspiring evidence of past volcanic

[1] The low density of the large outer planets shows that they are still in a gaseous state with possibly a small molten nucleus. Owing to their rapid rotation the dense clouds by which they are surrounded are whirled into more or less permanent latitudinal belts, which compose the only visible part of the planet. The belts on each side of the Equator exhibit more frequent changes than elsewhere. The Sun has a somewhat similar peculiarity, as the sun-spots and eruptive prominences are mainly confined to the same "sub-tropical" regions.

power. The eruption of Krakatoa, a few years ago, shook the Earth to its very centre and from pole to pole. Its upward cannonading was so terrific that it was heard 3,000 miles away, and it almost shot its projectiles into outer space. The Japanese earthquakes, even now, are active enough to cause the islands to be facetiously termed "The Lid of Sheol." Even the sputterings of Mont Pélée and Vesuvius are sometimes violent enough to inspire our respect. Who, then, can describe, or even imagine, the world-wrecking violence of the igneous forces when they were at the height of their strength and activity, before geology began?

On a much larger world than ours, with heavier rocks and a still denser atmosphere, the igneous forces are even more cramped than here, and the radiating surface is smaller in comparison with the mass. The process, therefore, continues for a much longer time, and the resulting evidences are comparatively insignificant.

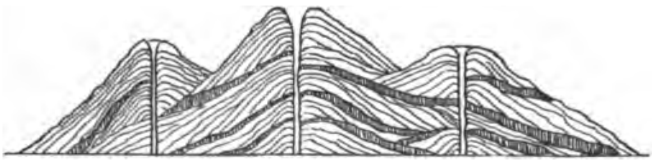


FIG. 115. — SECTION OF EARTHLY VOLCANOES
Built up of ashes and cinders, with interstratified lava streams.

But on a smaller world, like our Moon, the igneous forces appear to be practically unfettered. As the material there is only one sixth as heavy as it would be on our globe, it can be moved with only one sixth the effort.

If two volcanoes, one on the Moon and the other on the Earth, were each to eject the same kind of material with the same amount of force and under the same atmospheric conditions, the lunar projectiles would go six times as far as the earthly ones. But as there is no resisting atmosphere on the Moon, the lunar volcano will scatter its *débris* to an even greater distance than the difference in weight would indicate.

The result is that a violent, explosive, and long-continued eruption will not (as here) build up a huge mountain of *débris* with a small crater on its summit. It will tear out an enormous circular funnel-shaped hollow, surrounded by a massive rampart just at the edge of the volcano's field of force.

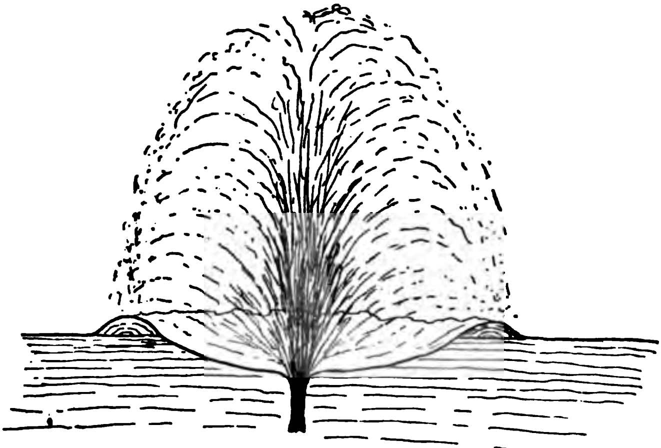


FIG. 116.—SECTION OF LUNAR VOLCANO IN FULL ACTIVITY

It may be well to give one or two illustrations of these differences in size and proportion between the earthly and the lunar volcanoes.

The largest volcanic crater on our globe is an extinct one in the Hawaiian Islands, that goes by the musical name of Haleakala. Its size, however, has been increased and its shape altered by an explosion like that which blew the head off the original Mount Vesuvius. The crater as it now exists is 7½ miles across, one way, and 2½ miles the other. It has an area of about 16 square miles, and the depth is about 2,700 feet. There are 16 conical hills scattered about its interior, from 500 to 600 feet in height. It is perched on the summit of a mountain 20 miles across and 10,000 feet above the sea-level.

In the southern part of the Moon is a crater to which has

FIG. 117. — CLAVIUS AND TYCHO

The former is the large walled plain near the bottom of the picture. The latter is the centre crater. It is the source of the chief lunar radiating streaks, which are only visible at full moon. Photographed at Yerkes Observatory.

been given the name of *Clavius*. It is one of the largest on our side of the Moon, and has several smaller and more recent craters scattered about its interior. It is more than 140 miles across, and has an area of about 16,000 square miles. Its rampart in some places reaches a height of 17,000 feet above the inside floor, which is about two miles below the level of the outside plain.

This crater, like all the very large ones on our side of the Moon, has no central cone. It is thought by some that these coneless craters are not the result of explosive volcanic eruptions, but that they were formed as seething lakes of molten lava, like the crater of Kilauea in the Hawaiian Islands.

There are many, however, which have inside cones, indicating that they are true volcanic craters. It may be as well to give the dimensions of one of the largest of these.

Theophilus, one of the most perfect craters on the Moon, is 64 miles across, and has an area of about 3,200 square miles. Some of the peaks on its rampart reach an elevation of 18,000 feet above the floor of the crater. One of the cone-shaped mountains in its centre is 6,000 feet high, yet its summit is 4,000 feet below the level of the outside plain. A number of similar craters are scattered around, but they are smaller or in a less perfect state of preservation. Besides these, there are swarms of craters so small that only a very powerful telescope will show them. But, *small as they are, they are equal in size to the craters of the largest earthly volcanoes.*

VARIETIES OF IGNEOUS ACTION

The solid crust which first forms on a solidifying world is more or less flexible on account of its thinness and high temperature. As it cools off and loses this flexibility it is cracked in all directions by the tides and other strains to which it is exposed. The cracks are filled up with molten rock, which sometimes reaches the surface and spreads over it in thin sheets. As this liquid matter cools and consolidates, it cements the crust solidly together again. The process goes on till the

whole shell is traversed in every direction with dykes and veins of mineral matter.

When the crust has become thicker, and the interior strains are greater, the molten matter exudes in greater volume from

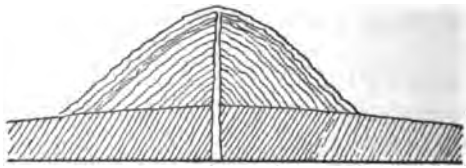


FIG. 119. — SECTION OF MOUNTAIN OF EXUDATION

the cracks. It solidifies quickly on the cold surface, and piles itself up in great heaps, forming ridges and sometimes *mountains of exudation.* The action is something like that of our mud-volcanoes, only the material is plastic through heat instead of water.

In time the molten nucleus becomes small, in proportion to the outside shell. It then contracts faster than the crust, and leaves the latter to fold and shrink upon it like the skin of a

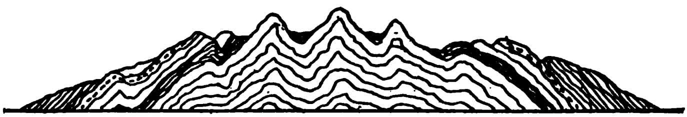


FIG. 120. — SECTION OF MOUNTAIN OF ELEVATION

wizened apple. This folding or crumpling produces what are known as *mountains of elevation,* consisting of more or less parallel ranges of folded rock.[1]

The molten matter, instead of exuding quietly up wide cracks to the surface, and there cooling off on the mountain slopes, is

[1] The character, distribution, and condition of these folded rocks will depend upon whether or not the world has a permanent atmosphere and a large amount of water on its surface. Also on whether it has any external source of heat and light, to keep those agencies in a state of activity.

Fig. 118. — Theophilus, a Lunar Crater-with-cone

64 miles across. Yerkes photograph.

now forcibly ejected from a series of blow-holes along the closed or choked cracks.[1] The result is that instead of piling up mountains of exudation it forms *volcanoes of eruption.*

The funnel-shaped hollow or crater formed at the top of one of these blow-holes is surrounded by a rampart composed of the ejected material. While the explosive force is increasing, the hollow gets larger, and the rampart is pushed farther back. The size of the crater is therefore a measure of the energy of the volcano at the height of its power, during its most violent paroxysms.

When the explosive force abates somewhat, small craters are formed inside the large one. When the violent eruptions give way to a quiet yet considerable oozing of molten rock, it fills up the crater till the rampart gives way, and then floods the surrounding country with more or less liquid lava. When there is not enough lava to overflow the crater, it simply solidifies inside, forming a nearly level floor. And when the lava flow is

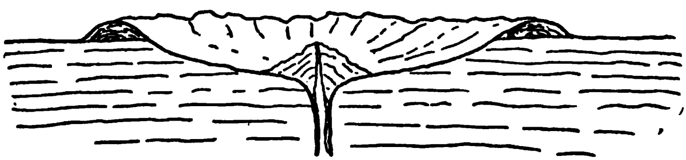


Fig. 121. — Section of Lunar Crater with Cone

too small or viscid to spread over the crater, it solidifies into conical peaks above the central vent.

Sometimes a volcano becomes inactive, not because the energy is exhausted, but because it is intermittent and the vent has become plugged up during a quiet interval. A subsequent disturbance, if powerful enough, will either blow out the obstruction or force a vent in some other part of the line of weakness. In the latter case the crust will be fractured afresh, and other

[1] The violence of its action depends largely on the quantity of water which gets to the hot interior, and on the volume and character of the gases produced by chemical action.

craters will be formed. The old one will then remain dormant or become extinct.

As the volcanic forces become exhausted, the craters formed are, of course, smaller than the old ones. And so at last the igneous action ceases to be visible on the surface of the now solid world.

The subsequent history of the world in question will depend upon the presence or absence of air and water in a state of activity. With them, the surface structures reared by igneous action will be gradually obliterated. Without them, the only changes will be landslides due to variations of temperature acting on the piled-up crater ramparts and precipitous mountain slopes. With this exception the volcanic structures will be perfectly preserved for as many millions of years as the petrified world containing them continues to have a separate existence.

CHAPTER XXII

LUNAR GEOLOGY AND GEOGRAPHY

"Speaking by our own lights, from our own experience and reasoning, we are disposed to conclude that in all visible aspects the lunar surface is unchangeable; that in fact it arrived at its terminal condition eons of ages ago; and that in the survey of its wonderful features, even in the smallest details, we are presented with the sight of objects of such transcendent antiquity as to render the oldest geological features of the Earth modern by comparison."—*Nasmyth and Carpenter*, "The Moon."

BIRTH OF THE MOON

WHEN the Moon still formed part of the Earth, the whole mass was probably in a molten condition, and surrounded by an extremely dense atmosphere which contained all the water now in the oceans, seas, and lakes. The atmospheric pressure must then have been equal to about 5,000 pounds to the square inch.

Owing to the rapid and increasing rotation the molten body was very much spread out at the equator, and the atmosphere was deeper and denser there than near the poles. The loss of internal heat by radiation was therefore greatest at and near the poles. This probably led to great convectional currents in the molten globe. The same cause led to atmospheric currents the lowest of which were from the northeast to the southwest in the northern hemisphere, and *vice versa* in the southern.

The attraction of the Sun, acting on the molten rock of which the rotating spheroid consisted, presumably raised a huge and ever-increasing tide on the side nearest to it. As the rotation quickened, this solar tidal wave of molten rock grew in size until it was finally thrown off and became the Moon, as described in a previous chapter.

Now the material which went to form the Moon was not taken from the heavy central metallic rock (8.2), but from the lighter envelope of molten silicates, with a density of a little over three times that of water (3.2). And the heavy atmosphere of steam and other gases was either retained or drawn back by the Earth on account of its superior size and attraction. The lunar silicates, however, were probably heavily charged with steam, etc., owing to the enormous atmospheric pressure to which they had previously been subjected.

The orbit of the new-born Moon gradually increased in size, from the tidal action. The molten silicates composing the Moon, being relieved from the tremendous atmospheric pressure, gradually expelled the steam and gases with which they were charged. They thus formed a huge globe of "boiling" rock, which cooled off on every side, by radiation into space, until the surface matter solidified.

THE GREAT PLAINS

The escaping gases, assisted by the earth-tides, probably broke up the first crust, and the fragments floated and drifted on the still molten surface. Large open lakes of boiling rock may thus have been left between them. These molten lakes would be something like that in the crater of Kilauea, but of vastly greater dimensions. They were sometimes many hundreds of miles across, and were more or less surrounded by rocky ramparts. These may have been built up of solid blocks driven to the sides by the violent ebullition and diverging surface currents.

In the course of time these hypothetical molten lakes cooled off and solidified. They form the dark level plains visible from the Earth with the naked eye. Before the invention of the telescope they were thought to be seas; and the Latin name for a sea has stuck to them ever since.[1]

[1] Even Kepler shared in this erroneous belief. In one place he says "Do maculas esse maria, do lucidas esse terras." Galileo, on the contrary, appears to have discovered that there are no visible bodies of water on our side of the Moon,

Fig. 122. — Mare Crisium, a Lunar Plain

Photographed soon after full moon. Lick Observatory.

Fig. 123. — Lunar Apennines and Alps

Lick photograph.

Most of these great plains have either a circular outline or are more or less surrounded by semicircular bays. *Mare Serenetatis* (the Sea of Serenity) is an example of the former, and *Mare Imbrium* (Sea of Showers) of the latter. This circular feature is not the result of accident. Whatever differences of opinion there may be as to the way in which they originated, it is certain that they are the result of (igneous or other) forces acting from local centres.

THE WALLED PLAINS

Mare Crisium, one of the smallest and most regular of the great plains, connects them with the crater-like *walled plains,* of which the best examples are known by the names of *Ptolemy, Grimaldi, Clavius, Schiller,* and *Schickard.* Most of these are over 100 miles in diameter.

In spite of the enormous surface dimensions of these walled plains, and of the fact that they have a practically level floor with no central cone, their appearance is so crater-like that it is impossible to draw a satisfactory dividing-line between them and the smaller volcanic craters which were subsequently formed. Their resemblance is so marked that it is evidently due to relationship.

RADIATING STREAKS

After the surface had cooled off and consolidated, the cooling process went on below, adding to the solid crust at the expense of the molten nucleus. The varying ratios of contraction, etc., gave rise to violent strains which resulted in immense cracks radiating in all directions from the local centres of force. The molten lava welled up through the cracks and spread over the

for his friend Milton carefully avoided mentioning lunar oceans and seas. He made Raphael watch the Earth —

> "as when by night the glass
> Of Galileo, less assured, observes
> Imagined lands and *regions* in the Moon."
> — "Paradise Lost," Bk. V.

surface for some little distance in thin watery sheets. These of course soon solidified, and are now visible when the Moon is at its full.

MOUNTAINS OF EXUDATION

At a later time, when the conditions were rather different, the solid crust appears to have been again fractured in some parts of the Moon, and immense quantities of molten lava welled out onto the surface. There it cooled off and solidified, like spring water that comes to the surface in a severe frost. In this way long ridges of solidified lava were formed, with open vents all along the summit. Through these vents the quiet *exudation* of lava continued until the ridges became mighty ranges of mountains. Such are the *Leibnitz Mountains*, in the extreme south of the Moon. These have an elevation of 31,000 feet above the general surface. They are therefore higher in proportion than any mountains on the Earth.

Another important range is known as the *Lunar Apennines*, a little to the north of the centre of our side of the Moon. It is an extremely wild and precipitous range of mountains about 480 miles long and of considerable width. It contains about 3,000 peaks, which probably represent the widest parts of the elongated cracks through which the liquid silicates rose to the surface. Some of these summits are 18,000 feet above the level of the plains below.

The *Caucasus Range* and the *Lunar Alps* are similar mountains of exudation. The latter range contains 700 peaks and is almost cut in two by a remarkable straight valley with a level floor and precipitous sides 11,000 feet high. It is 80 miles long and about 5 miles wide at the bottom.

With perhaps the exception of the first mentioned, all these ranges of mountains have a steep precipitous slope toward the Moon's west,[1] and a long gradual slope on the side toward which they are carried by the Moon's rotation. In this respect they resemble the Andes of South America.

[1] Toward the east as seen from the Earth.

Fig. 124. — Copernicus

By Nasmyth and Carpenter. (*From " The Moon," by Nasmyth and Carpenter, published by John Murray.*)

ISOLATED PEAKS

A few isolated peaks were also formed, perhaps by the same quiet exudation of rather viscid lava. They rise rather abruptly from the level plain, like some vast cathedral. There is one in the north which goes by the name of *Pico*. It rises almost precipitously to a height of 8,000 feet.[1]

EXPLOSIVE VOLCANIC ERUPTIONS

After these mountain ranges and isolated peaks had been more or less quietly formed on the northern plains the increasing shrinkage of the nucleus appears to have closed up the wide cracks and made egress to the surface more difficult. The result was that the volcanic forces became violent, and the molten lava, instead of quietly oozing up all along the cracks, was forced up explosively at distant centres. Owing to the feeble gravitation, and to the absence of atmospheric pressure, the resulting volcanic craters were so tremendous in size that we have nothing on Earth anywhere approaching them.

After the volcanic forces had passed their maximum the large craters were choked up, and smaller ones were formed on their flanks, to be in time superseded by still smaller ones. There are sometimes strings of them, evidently formed along the same crust-fractures.

QUIET VOLCANIC EXUDATIONS

The explosive volcanic eruptions were sometimes succeeded by the quiet exudation of lava through the same volcanic vents. Where the flow was very abundant the crater was filled till the lava broke down the rampart and flooded the outside plains. In the case of one crater, which has been named *Wargentin*, the lava rose to the very brim of the crater and there solidified, forming a round table-mountain 53 miles across.

[1] The lunar peaks are not really as precipitous as one would think from the long shadows they cause.

In cases where the flow of lava was less abundant the craters were partly filled up, and have now either a level or a slightly convex floor.[1] Very often this has a number of little craters scattered about it, and has also a cone, or series of cones, over the central vent.

As no two of the lunar craters were formed under exactly the same conditions, it is not surprising to find that each one has an individuality of its own. Yet if we except the great differences in size, which are easily explained, it will be found that their resemblances are much more marked than their differences. There is not the shadow of a doubt as to their volcanic origin, and geologists can learn many a lesson as to the history of the Earth by studying the volcanoes on the Moon.

OPEN CRACKS

After all volcanic activity had died away on the Moon's surface (and probably after the Moon had solidified to its centre), large numbers of surface cracks were formed by the continued contraction. Many of them are of such a tremendous size that they are visible to our telescopes. Some can be traced for more than a hundred miles, being from one to two miles wide and of great but unknown depth.

These open cracks in some cases cut clear through the previously formed craters. Not only are some of the large and early craters thus intersected, but also some of the small and more recent ones.

With the formation of these open cracks the Moon's activity apparently ceased and it became what it is to-day — and what our Earth will be to-morrow — *a dead world.*

TYPICAL FEATURES

The study of lunar geology leads naturally to lunar geography, which is its product. The principal features can be best learned with the help of a good telescope, assisted, *and preceded,* by

[1] Due to imperfect fluidity.

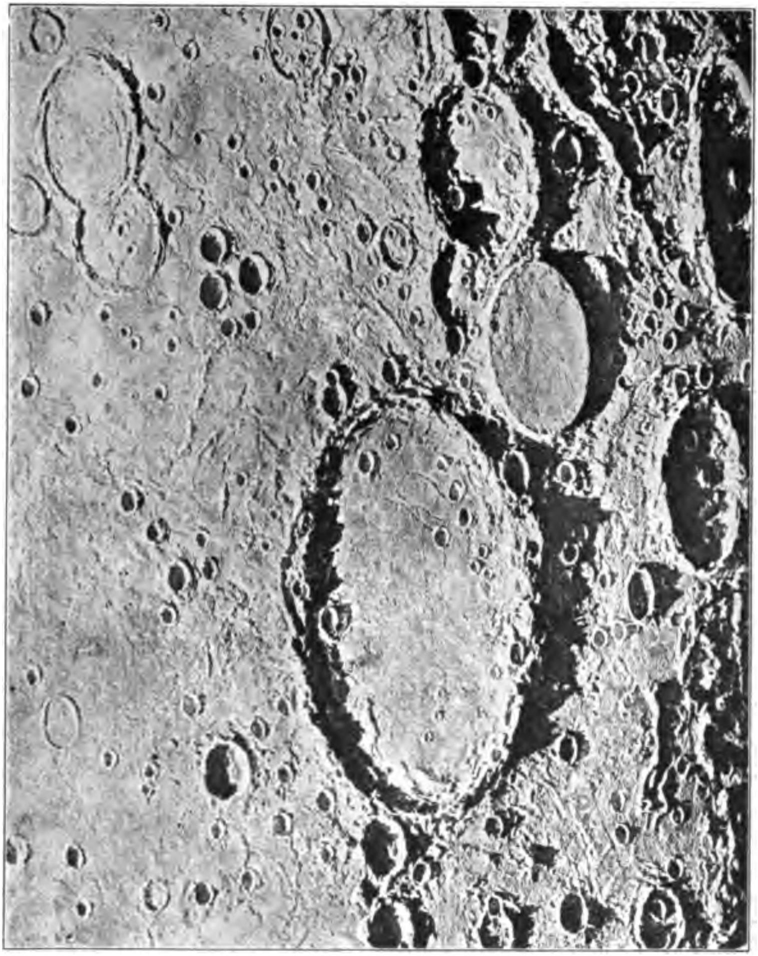


Fig. 125. — Schickard and Wargentin

By Nasmyth and Carpenter. *(From " The Moon," by Nasmyth and Carpenter, published by John Murray.)*

the study of lunar charts and photographs. It may be well, however, to point out some of the best illustrations of the peculiarities already mentioned.

The *Great Plains* are conspicuous objects on account of their great size and dark hue. Most of them can be made out with an opera glass, or even with the naked eye. Their names will be found on the lunar charts at the end of the book.

The *bright streaks* which have been mentioned radiate from the craters which bear the celebrated names of *Tycho*, *Copernicus*, *Aristarchus*, *Kepler*, and *Proclus*. These craters developed after the streaks were formed, but owe their positions to the weakness and open state of the crust at the centre of fracture.

There are over 100 streaks radiating from Tycho. They spread over a great part of the Moon's surface. One of them passes under the distant crater *Menelaus*, stretches clear across the "Sea of Serenity," and is finally lost to sight at the northern edge of the Moon.

The streaks radiating from Copernicus are next in importance. They are so intricate as to be uncountable.

The Aristarchus streaks appear to have been formed after those of Copernicus but before those of Kepler.

The *craters-with-cones* vary in size from the giant *Petavius*, 78 miles across, to the little companion to *Hell*, 1¾ miles in diameter. There are probably many smaller ones which the telescope fails to reveal.

Copernicus, 56 miles across, is one of the grandest objects on our side of the Moon. It is remarkable not only for its radiating streaks, but also for the landslides on both sides of its rampart, for its radial spurs extending for 100 miles, for the open cracks in its neighbourhood, and for the thousands of tiny craters which surround it.

Plato, 60 miles across, is a *coneless crater* easily recognised, at full moon, as a dark oval spot near the northern edge. Like all other craters, it is better seen when the sunshine falls on it at an angle, and throws the black shadows of its sur-

rounding peaks on the smooth inside floor and on the hill country beyond. It has a considerable landslide on the inner side of its rampart, and there are thirty very small craters scattered about on its level floor. The Lunar Alps are close by, cut in two by the curious straight valley already mentioned.

Aristarchus, 28 miles across, is as easily recognised by its brilliant chalk-like hue, that almost dazzles the eye. The surface outside appears to be folded into parallel ridges, and there is a curiously contorted crack, not far away, which is about two miles in width.

Ptolemy, *Alphons*, and *Arzachael*, near the centre of ou- side of the Moon, form one end of a more or less continuou chain of large craters extending to the south. Near the last named is a huge circle with a scarcely perceptible rampart. Across this almost smooth circle there runs what looks like a straight railroad embankment, about 60 miles long and 2,000 feet high. From its artificial appearance it is commonly known as *The Railway*.

Every part of the Moon's surface is full of objects that are interesting when seen through a good telescope with the right illumination. With the exception of the bright streaks, all the lunar features are best observed when they are near the changing "terminator," so that the light falls on them at an acute angle.

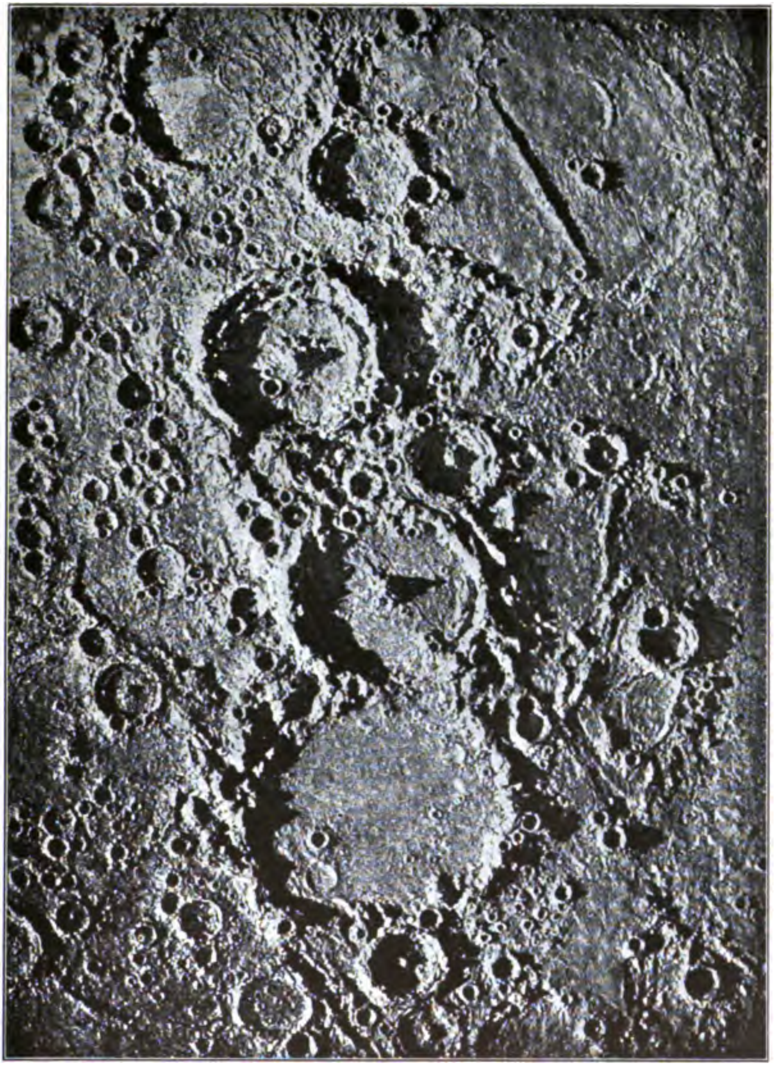


Fig. 126. — Ptolemy, Alphons, and Arzachel

By Nasmyth and Carpenter. ***(From " The Moon," by Nasmyth and Carpenter, published by John Murray.)***

CHAPTER XXIII

INHABITED WORLDS

"As there are other globes like our Earth, so there are other [family groups] like our Solar System. There are self-luminous suns exceeding in number all computation. The dimensions of this Earth pass into nothingness in comparison with the dimensions of the Solar System, and that system, in its turn, is only an invisible point if placed in relation with the countless hosts of other systems. Our Solar System, far from being alone in the Universe, is only one of an extensive brotherhood, bound by common laws and subject to like influences. Even in the very verge of creation, where imagination might lay the beginning of the realms of Chaos, we see unbounded proofs of order, a regularity in the arrangement of inanimate things, suggesting to us that there are other intellectual creatures like us, the tenants of those islands in the abysses of space."—*Dr. J. W. Draper*.

ARE OTHER WORLDS INHABITED?

IN ancient times our Earth was supposed to be the only world in existence. In fact the Universe was thought to consist solely of our Earth and its appendages. But in the course of time it was discovered that the Earth is only one member of a family of worlds, and that there are other families of worlds outside of our own.

These two discoveries naturally gave rise to a lively discussion as to whether those worlds are, as a rule, inhabited by living organisms.

At first, pride and theological prejudice led many people to deny emphatically the existence of any kind of life on other worlds. Even after the consideration of probabilities had led to the abandonment of this position, the existence of *rational* life was strongly contested.

After this came a time when the most progressive minds went to the other extreme. They claimed that life probably

exists on every world of any size, at a certain stage in its development.

The first of these extreme views concerning the plurality of worlds has long been abandoned by all intelligent and well-informed persons. The last is now being somewhat modified by astronomers. They consider that, while it is absurd to suppose that our Earth is the only inhabited world in the Universe, the opposite extreme is not supported by the available evidence as to the conditions existing on other worlds.

While the extreme affirmative side was in the ascendency, certain imaginative astronomers (and other imaginative persons who were not astronomers) stated that they had recognised indications of life on the Moon. A little later, some of our very best observers constructed charts of Mars showing the dark markings on it connected together by very artificial-looking "cobwebs." Schiaparelli gave the Italian name *canali* (meaning "channels") to these elusive markings. English-speaking people mistook the Italian *canali* for the English word "canals," and jumped to the conclusion that Mars is inhabited by very enterprising engineers who eke out a small water-supply by means of large irrigating canals. The theory was afterward made less absurd by the supposition that the markings were not the canals themselves, but the belt of vegetation on each side of the main ditch.

Made enthusiastic by this supposed identification, one or two sensational astronomers went a step farther, and asserted that the Martians were trying to attract our attention by displaying geometrical signals constructed on a world-wide scale.

The supposed evidences of life on the Moon were easily proved to be wholly imaginative. In one rather notorious case, indeed, they turned out to be nothing but a hoax, gotten up to test the credulity of the general public.

With regard to the "canals" of Mars, the belief is now growing stronger among astronomers that they are largely subjective phenomena — that in fact the majority of them are optical delusions caused by the observers over-straining their eyes in

the effort to make the best use of their telescopes. The rest of them are probably due to close sequences of spots too faint to be separately visible.

The truth appears to be that our optical appliances, powerful as they may be, are yet very far from the degree of perfection required in order to detect evidences of life in other worlds. The probability is that they always will be unequal to the task. We have therefore no means of actually proving or disproving the theory that other worlds are inhabited. There appears to be some positive evidence that the Earth is inhabited, and that its Moon is not. But apart from these two planets we have no actual positive evidence that life exists, or does not exist, anywhere in the Universe. *And we never shall have.*

This being the case, about the only way we can deal with the problem is to try to find out the conditions necessary for life as we know it, and to see whether those conditions exist on any of the other planets in our System. We shall then be in a better position for speculating on the probability, or otherwise, of these worlds being inhabited by living organisms allied to those on our Earth.

When that question is disposed of, there will still remain the more obscure problem whether any of the worlds are tenanted by entirely different forms of life.

ESSENTIALS TO LIFE AS WE KNOW IT

Among the things which are absolutely essential to organic life here are the four elements known as *carbon*, *hydrogen*, *nitrogen*, and *oxygen*.

Of these, *oxygen*, in a free gaseous state, is essential to all forms of *animal* life.

Carbon and *oxygen*, in combination, form *carbon-dioxide* (CO_2), which, as a gas, is equally essential to all forms of *vegetable* life.

Hydrogen and *oxygen* combine to form *water* (H_2O), which both plants and animals require in a liquid state.

Carbon and *hydrogen* form the basis of numerous compounds which, by their formation and oxidation, alternately accumulate energy and expend it in motion, etc. These two processes are together known by the name of *energy-traffic.*

Nitrogen is necessary, in a free gaseous state, to keep in check the all-devouring energy of free oxygen. It is also necessary, in combination with the hydrocarbons, to regulate and control their energy-traffic. It is specially adapted for this office on account of its sensitiveness to changes of energy and the resulting instability of its compounds.

All the life on our globe is based on *protoplasm,* which consists of these four elements. A number of other elements occur in most forms of life, but do not seem to be so essential to it.

An *intermittent* supply of *radiant energy* also appears to be necessary to life as we know it. The plants derive their energy, either directly or indirectly, from the Sun, and the animals get it at second-hand, from the plants.

The energy-traffic mentioned above can only be carried on within a certain *range of temperature.* Life based on protoplasm cannot exist where the temperature is permanently above 150° F., or below 32° F. High temperatures break up the protoplasm into less complex compounds. Low temperatures check and eventually put a stop to its activity.

A certain intensity of the force of gravitation also seems to be essential to life as we know it. For worlds which are very much smaller than ours do not appear to be able to retain the vapours and gases necessary to living organisms, and on worlds that are very much larger, the same organisms would be crushed to death by their own weight.

DO LIFE-ESSENTIALS EXIST ON OTHER WORLDS?

When we examine the other planets in our System, we find that some of these essentials are lacking in every one, and always will be lacking.

0° Fastigium Ceryor

30° Margaritifer-Sinus

60° Ganges

90° Solis Lasus

120° Nodus Gordii

150° Mare Sirenum

FIG. 127. — TWELVE VIEWS OF MARS

By Lowell. (*From Todd's "Stars and Telescopes," published by Messrs. Little, Brown, & Co.*)

180° Atlantis

210° Trivium Charontis

240° Hesperia

270° Libya

300° Syrtis Major

330° Phisoner Euphrates

FIG. 127. — TWELVE VIEWS OF MARS

By Lowell. (*From Todd's "Stars and Telescopes," published by Messrs. Little, Brown, & Co.*)

Our nearest neighbour, the *Moon*, shows no signs of having either air or water. This is probably due to the fact that it is unable to retain them, except in a solid state. Owing to their absence, and to the slowness of the planet's rotation, the range of temperature is too great for any form of life based on the carbon compounds.

Mercury and *Mars* probably have a very scanty supply of both air and water. There are no perceptible oceans or seas on Mars, and Dr. Campbell, of Lick Observatory, has shown that the atmospheric pressure on its surface is very small. It appears, in fact, to be less than that at the summit of Mount Everest, the highest mountain on our globe. This being the case, it is possible that the planet is unable to retain the vapour of water, and that its "snowy poles" are nothing but frozen carbon-dioxide (CO_2), an inch or two in thickness.

Venus probably has a good supply of both air and water. But as it appears to keep one side always turned to the Sun, it has not the *intermittent* supply of radiant energy which is necessary for life on our globe. The Sunward side must be too hot for protoplasm to exist, and the dark side must be cold enough to freeze both water and air. Mercury also appears to possess the same unfavourable coincidence between its rotation and revolution.

The *Asteroids* receive much less light and heat than the Earth. They have probably neither air nor water, as their gravitation is too small to prevent these from escaping into space, as free hydrogen does from our Earth.

Jupiter may be said to be all atmosphere, as it appears to be still in a hot gaseous state, surrounded by thick cloudy condensations. The intensity of the Sun's light and heat is 27 times less there than on our Earth. Its five moons must therefore appear as mere wandering stars.

Saturn is not as dense even as Jupiter. And it is still less favourably situated as regards solar radiation, in spite of its enormous satellite-rings and numerous moons. For the intensity of solar light and heat is 90 times less than here.

Uranus and *Neptune* are little more, at present, than huge masses of rotating gas, slowly revolving in the gloomy outskirts of the Solar System. The intensity of Neptune's sunshine is 900 times less than that which we enjoy. Its lot would therefore be a cold one if it were not for its store of internal heat, continually replenished by the gradual contraction of the planet.

This concludes our survey of the Solar System in search of the essentials of life. If we wait until the outer planets have reached the present stage of the Earth, we shall still find the conditions utterly unfavourable to life as we know it. For the force of gravitation will still be tremendously greater than here, and the radiant energy from the distant and waning Sun will then be insufficient to keep the otherwise dense atmospheres from settling down over their entire surfaces, in a solid mass of never-melting "snow."

We have then good reason to think that in our own System the Earth is the only planet on which the conditions are favourable for life *as we know it*. That is to say, *if* life must necessarily be based on protoplasmic combinations of oxygen, hydrogen, nitrogen, and carbon, the other planets in our System appear to be uninhabitable.

Among the many millions of solar systems which surround our own, it may be regarded as certain that there is no single world where the conditions are *identical with* those on Earth. But it is possible that there may be quite a number of worlds where the conditions are somewhat *similar to* those found here.

In such worlds we should probably find living organisms based on the same four elements, but developing along somewhat different lines. For earthly forms of life have grown up under certain conditions, and cannot exist where those conditions do not prevail. On other planets life would start under different conditions and develop accordingly. In other words, the various forms of life on our globe are the result of *general laws* operating under *special conditions*, and the same general

laws would, under different conditions, result in different forms of life.

But although the number of such worlds in the Universe may be *numerically* large, it must be *relatively* small. We know that the Universe contains hundreds of millions of luminous suns, and we have reason to believe that they are many times outnumbered by dark planetary worlds. Let us deduct from these latter the comparatively small number on which the conditions are presumably somewhat similar to those on our Earth. The question now remains whether the rest are entirely without life of any kind, or whether they are tenanted by forms of life which are based on other elements and require altogether different conditions.

For my part, I must say that the latter seems the most reasonable supposition, considering the resourcefulness of Nature in our part of the Universe. Yet we have reason to believe that even our World is entirely uninhabited, except on the thin surface layer. And it is only habitable there for a comparatively short time. Nature may be as wasteful of worlds as it is of sunshine.

The fact is that we none of us know anything at all about this last question. *And we never shall know.*

WHERE IS THE EARTH?

"*Beelzebub.* 'There is a place
(If ancient and prophetic fame in heaven
Err not), another world, the happy seat
Of some new race, called *Man*.
. . . .
Thither let us bend all our thoughts, to learn
What creatures there inhabit, of what mould
Or substance, how endued, and what their power.'
. . . .
Satan. 'Whom shall we send
In search of this new world? Whom shall we find
Sufficient? Who shall tempt with wandering feet
The dark, unbottomed, infinite abyss,
And through the palpable obscure find out
His uncouth way, or spread his aery flight

Upborne with indefatigable wings,
Over the vast abrupt, ere he arrive
The happy isle?

. . . .

I abroad
Through all the coasts of dark destruction seek
Deliverance for us all: this enterprise
None shall partake with me.'" — *Milton*, "Paradise Lost," Bk. II.

So far the entire subject of inhabited worlds has been treated from an earthly standpoint. It may be an advantage to consider it briefly from the outside.

Let us suppose for a moment that our Earth is the only world in the Universe which is inhabited by living organisms. And let us suppose that from some distant spirit-land a flying messenger is sent to hunt up our World, without any special instructions for finding it. Let us also suppose that he can travel through space at a speed equal to that of light. He may travel from star to star, for hundreds, thousands, and millions of years, without being able to find it. If in the course of time he comes to our System, he may see the larger and more showy planets, and yet fail to notice our little World.

If it were to be pointed out to him as the specially favoured world, he would hardly be able to convince himself of the fact without a close examination. For the only unusual feature about it, as seen from a distance, would be that it was attended by a satellite which was large in proportion to its primary. Apart from this peculiarity, which may be common in other systems, the Earth would seem to be merely an insignificant attendant on a star which was itself almost indistinguishable from millions of other stars.

That our Earth is the only inhabited world is therefore an extremely unlikely supposition to be entertained by anyone who is at all conversant with the dimensions, construction, and duration of the Universe. It appears reasonable only to one who is almost entirely ignorant of all except his immediate surroundings.

Yet there are people on our Earth (even in so-called enlight-

ened and civilised countries) who not only think that it was created expressly for the use of man, but also believe that the entire Universe — visible and invisible — was made for his service and edification! There are persons who actually believe that the Sun was made to rule an earthly day, the Moon to adorn an earthly night, the planets to serve as oracles of earthly fortunes, and the stars to relieve the monotony of an earthly sky! The sciences of astronomy and geology show that — natural as these ideas may seem to unenlightened people — they are as baseless as the airy fabrics of a midnight dream.

SUMMARY

Dr. F. J. Allen, in a recent article in the "Popular Science Monthly,"[1] has ably summed up the argument as to "Life in Other Worlds." He says:

"1. If life is essentially a function of the elements nitrogen, oxygen, carbon, and hydrogen, acting together, then it can probably occur only on exceptional worlds, with conditions closely resembling those of our own Earth. Such conditions are not present in any other world in our own Solar System, nor can they be expected to occur frequently in members of other systems.

"2. On the other hand, if different conditions can awaken a capacity for exalted energy-traffic among other elements than those just named, then the Universe seems to provide immense possibilities of life, whose variety and magnificence may far exceed anything that we can imagine."

OTHER-WORLD SPECULATIONS

I think that it has now been satisfactorily shown that we have no direct knowledge whatsoever concerning inhabited worlds outside of our own, and that we are never likely to obtain such knowledge.

But on the other hand it has also been shown that it would be preposterous to suppose our Earth to be the only inhabited

[1] November, 1903.

world in the Universe. As a matter of probability, we may safely take it for granted that there are, at the present time, myriads of inhabited worlds, a certain percentage of which have developed reasoning beings. We may also take it for granted that there have been myriads of such worlds in the limitless past, and will be in the limitless future.

This being so, the question naturally arises, is the life on those worlds likely to develop along the same lines as here, or has each world its own special line of development, not conceivable by the inhabitants of any other planet? In other words, is it probable that a visitor to one of those worlds would there find two ascending series of organisms, the one culminating in flowering shrubs and trees, and the other in backboned quadrupeds, headed — and more or less controlled — by a reasoning biped like man?

At first sight it does not seem as though any time could be profitably spent in considering the question. It looks, indeed, as though it would be only another case of arguing about the politics of the people who live — or do not live — on the other side of the Moon.

Yet a close study of the development of life on our Earth appears to afford considerable indirect and circumstantial evidence that the course of organic evolution may be very similar, even where the physical and chemical conditions are widely different. This similarity is rendered probable by the fact that organic peculiarities, both internal and external, have not been developed so much by the inorganic as by the organic surroundings. *The evolution is mainly the result of a struggle for existence, which must go on wherever there is life.* Therefore if the physical environment be a tolerably permanent one, favouring the processes of organic chemistry, the resulting life-forms may be similar, whatever may be the temperature or the active chemical elements.

On our Earth, Nature has long been unconsciously experimenting with innumerable kinds of organic life. Without either mercy or spite she has pitted one form against the other

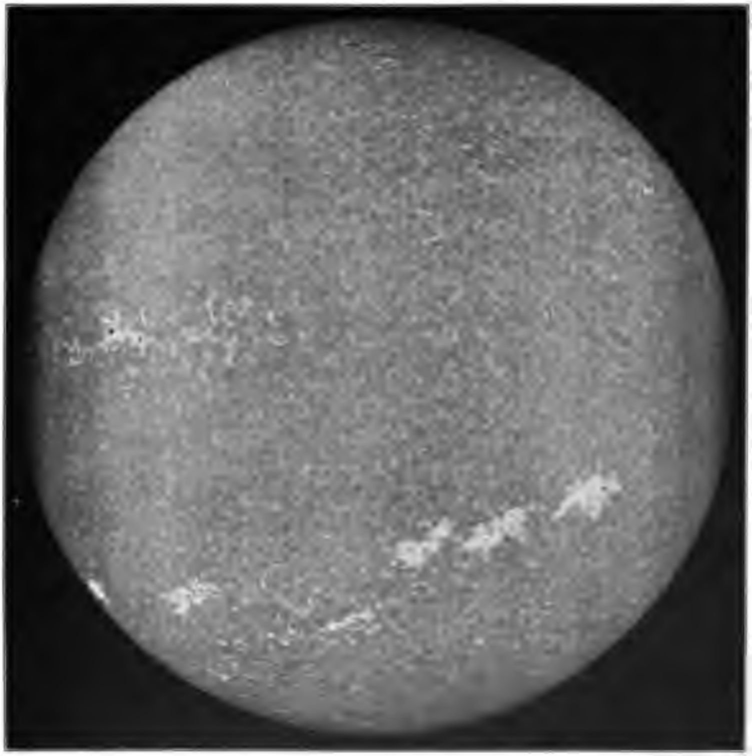


Fig. 128. — Disc of the Sun, August 12, 1903

Showing brilliant calcium flocculi. Middle (H) level. Taken with Hale's spectroheliograph, at Yerkes Observatory.

under a great variety of local conditions, allowing the fittest to survive and the rest to perish. The "experiments" have been ceaselessly carried on for many millions of years, with a superabundance of material, and with a physical and chemical environment that has been almost unchanging.

This being the case, the course of development and final result may have been inevitable rather than the effects of chance. Earthly forms of life may be practically duplicated on a million worlds — that were, and are, and are to be.

There is not room in this chapter to go into details on the question, and it would be out of place in any other part of this volume. But a few hints may be given as to the way in which organic life is likely to develop on a world where the conditions prove favourable.

Whatever the temperature and active elements may be, it seems certain that organic life must be based on the cell or its equivalent, and that the first cells must originate from and in non-living compounds of those active elements.

A. The first living forms must be single-celled PROTISTA, having their home in water or some similar fluid.

The energy necessary to carry on the processes of life must come from a chemical change similar to the oxidation of tissues. The wasting tissues must be renewed by the absorption of soluble inorganic compounds.

Each single-celled organism must go through a life-cycle ending either in death or in division. This must lead to reproduction by fission, or by some similar process involving a less expenditure of energy than the original spontaneous generation.[1]

The multiplying individuals must adjust themselves to local conditions, and thus give rise to varieties, species, etc. When they have multiplied till food becomes scarce, some will be compelled to feed on their neighbours. Only those will survive which can obtain food and protect themselves from being eaten. The result of this "cannibalism" is a division into

[1] And capable of being carried on under less favourable conditions.

plants, which live on soluble inorganic food, and *animals*, which live, either directly or indirectly, on the plants.

When single-celled possibilities have all been long and fully tried, the only possible advance will be found in combination. Some of the dividing organisms will remain in contact and partnership, giving rise to many-celled plants and animals. These compound individuals will — by co-operation and division of labour — find greater safety and economy, resulting in a better living than their simple competing neighbours. They will therefore get the upper hand, and continue to advance in size and complexity of organisation.

Nature may be said to have issued two irrevocable decrees with regard to organic evolution. One of these is that "where there is no necessity there shall be no development." The other is that "where there is necessity there shall be either development or death."

The *plants* — living by the absorption of soluble inorganic compounds, which are all around them — require no special-sense organs, or apparatus for thinking, moving, eating, digesting, etc., and they do not develop them. But they are usually compelled to anchor themselves to the sea-bottom where the surroundings are favourable, to spread themselves out so as to obtain a large absorbing surface, to protect themselves from their animal foes, and to modify their methods of growth and reproduction wherever the local conditions require it.

The *animals* — being compelled to find suitable organic food or starve — will develop means of locomotion and all the physical and mental peculiarities necessary for obtaining and utilising the available supply. Like the plants, they will find it necessary to protect themselves from their animal foes, and to modify their methods of growth and reproduction wherever the local conditions require it.

The animals will therefore rise to a higher plane than the vegetables, and the free-moving and offensive forms will develop more, in every direction, than the fixed, sluggish, and defensive forms.

So far as shape is concerned, there appear to be only two general organic types possible, either here or in any other world. These are the *radial* and the *elongated bilateral.*

Among the animals, the *radial type* has given rise, on our planet, to two branches.

B. One of these is termed the CŒLENTERATA. It contains such forms as the *jelly-fishes, sea anemonies,* and *corals.* These have only one opening to the stomach.

C. The other branch is the ECHINODERMATA. It includes the *crinoids, starfishes,* and *sea-urchins.* They have the stomach open at both ends.

All the forms in these two branches are either fixed or sluggish. Other-world forms of this radial type would probably be the same.

The *elongated bilateral type,* although very unpromising in its earlier stages, has much greater possibilities. In fact all our higher forms of animal life belong to this type.

D. The simplest form is that of a marine *worm,* which is little more than a long sack with a hole at each end of it. At this stage it is naturally a very sluggish animal.

E. When the worm-like animal develops tentacles or arms around its mouth, it becomes a MOLLUSK, represented on Earth by the *clams, snails,* and *cuttle-fish.* Some of these forms are rather more active than those already mentioned, but the limit of advancement is soon reached.

F. When the worm-like form develops a segmented structure, with a tough skin, and numerous jointed legs arranged along its two sides, it becomes the more active ARTHROPODA, represented in our seas by the *lobster* family and some *insects.*

G. When the same worm-like form retains its simpler structure but develops an internal skeleton, with a tail and two pairs of lateral limbs, it becomes a VERTEBRATE *fish*-like animal. This is capable of great activity, and appears to be the highest form of life which can be developed under oceanic conditions.[1]

[1] For many millions of years this fish-like vertebrate has made very little progress with us, in spite of the relative immensity of our oceans and the great

From this it appears probable that on those worlds which are nearly or entirely covered by water or some similar liquid, the highest form of life will be a rather stupid fish-like animal with an internal skeleton, simple organisation, a tail, and two pairs of lateral fins.

On those planets which have large masses of land rising out of the ocean, some forms of life will be gradually crowded out of the water and modified so that they can live without being constantly submerged. In the course of time both plants and animals will spread over the continents and islands, relying on an occasional rainstorm to keep them from drying up.

On our Earth, only the elongated worm-like type sent representatives out of the water to seek a living on the dry land. Its four branches (*D*, *E*, *F*, and *G*) now constitute the entire population of the dry land, as well as all the more active residents of the ocean. The arthropods and vertebrates have been the most successful of the dry-land colonists, and have risen, both physically and mentally, far above their relatives who still remain below the sea level.

Most of the dry-land ARTHROPODS became parasites of the land vegetation.[1] As a result of the struggle for existence they developed into an immense variety of *insect*-life. At the same time they compelled the plants to protect themselves, and so caused the development of an equally immense variety of *flowering plants*. But their complex organisation and parasitic mode of life limited their size and prevented them from developing further than the *bee* and the *ant*. On other worlds the same causes would probably result in similar limitations.

It would be a mistake to suppose that the animal with the most complex organisation is necessarily the highest and most progressive form of life. The most progressive animal, both physically and mentally, is likely to be the one which has the

variety of forms which have arisen therein. Its development appears to have been checked by the limitations of its habitat. Even the land mammals which have gone back to live in the sea have degenerated, both physically and mentally.

[1] Some of them afterward became parasites on other animals.

very simplest — and best arranged — machinery that is really effective in accomplishing the desired ends.

On our world the arthropods, with their many segments and numerous limbs, were compelled (like the fishes in the sea) to waste their energies in mere multiplication of non-progressive species. The fish-like VERTEBRATES, on the other hand, with their simple, well-arranged, and centralised organisation, and with the smallest effective number of limbs, made rapid progress as soon as they had adapted themselves to living on the dry land. Their gills were replaced by lungs, and their lateral fins developed into legs, with five toes on each foot. The more varied conditions to which they were exposed in their new habitat, combined with the violent struggle for existence which soon arose, led to great developments in size and strength or in nimbleness and cunning. Their internal organs became more effective, and their organs of sense more acute. They developed into *amphibians*, *reptiles*, *birds*, and *mammals*. Many of them became carnivorous, and developed claws and teeth suitable for their bloodthirsty profession. This led to the survival of those vegetarian forms which were most successful in defence, concealment, or flight. A great variety of species arose from this struggle for existence.

Some of the tree-dwelling quadrupeds learned to use their feet for climbing, and for swinging from tree to tree. When they were subsequently forced to live on the treeless plains, they walked upright on their hind legs, and used their front feet for grasping weapons and tools. Their mental development was so much hastened by this new use for their front feet that they gradually learned to utilise the forces of Nature in addition to their own strength. They also learned to convey their thoughts to one another by a constantly increasing variety of vocal sounds, and mutually to co-operate for the attainment of any desired end. As they were now able to protect themselves from the elements, and from all kinds of difficulties and dangers, they soon spread from land to land without undergoing any great physical modifications. Their descendants are

now to be found all over the continents and islands of the Third Planet, and the species is known to science by the name of *Homo sapiens.*

Now the innumerable modifications that have, on our Earth, led from the first protista to the latest man, are entirely the result of the struggle for existence. This struggle may at the very first have been entirely physical and chemical. But when once any particular part of the World became crowded with living organisms, there arose *a much more terrible struggle,* between the different species, and also between the individuals composing those species. This struggle was one for the necessaries of life, such as food, water, air, and light. All kinds of organic life were blindly and intensely prolific, but the World was small, and the necessaries of life were strictly limited in amount. The entire Earth therefore became like the Black Hole of Calcutta, packed with a struggling mass of starving and suffocating organisms. For every one that lived long enough to propagate its species, a thousand perished in infancy. Only those that were strong, savage, nimble, cunning, unscrupulous, or uneatable, could survive and hand down their peculiarities to their posterity. The surviving forms are therefore those which are best fitted to carry on the struggle.

The physical and mental peculiarities which have been most successful here would probably be most successful in a similar struggle for existence on any other world. And the course of organic evolution would therefore be somewhat similar. Hence we may say, with George Morris:

> "There is considerable reason to believe that the beings which answer to man upon any of the planets of the Universe must at least approach man somewhat closely in physical configuration. . . . It certainly seems as if a human traveller, if he could make a tour of the Universe, would find beings whom he could hail as kindred upon a thousand spheres." [1]

[1] Those who wish to follow up this subject should read an article by Mr. Morris in the *Popular Science Monthly* for April, 1904.

A POET'S DREAM

The astronomer, as such, has nothing to say of the unknown citizens of these unknown worlds. Accustomed, as he is, to test his theories by observation, he holds lightly to unprovable speculations, however probable they may be.

The speculative poet, however, trusts himself in airy flights that extend far beyond the limits of the known. He not only wrestles boldly with half-seen facts, but also concerns himself with invisible probabilities. With an imagination that knows no fetters except those of natural law, he sees, beyond the utmost range of telescope and camera, the —

— "fire of unrecorded stars
That light a heaven not our own."

He beholds, with a certainty that is based on mathematics and physics —

— "the hidden gyre
Of bulks that strain in Algol's toils."

He glimpses, with a probability that is born of his earthly observations, the —

— "seas that flash on alien eyes
The riven sunlight of Altair."

In many a far-off globe he sees a dawn of life, followed by a physical and mental evolution which culminates in the development of reasoning beings. On many an unknown world he watches an age of faith slowly change to an age of reason. On many a sun-kissed planet he hears infantile stories of a one-world creation give way to more mature discussions of a vast and abiding Universe. He imagines these unknown philosophers discussing the whence, the where, the what, the why, and the whither of all things — even as some of us do here.

He sees these lengthy discussions brought to a futile close by the gathering darkness and cold of everlasting night — to be as

fruitlessly brought up, again and again, on other worlds, in systems yet to come. For the great "Riddle of the Universe" can never be fully solved by finite minds. As Olive Schreiner says of the drama that is being enacted on our own Earth :

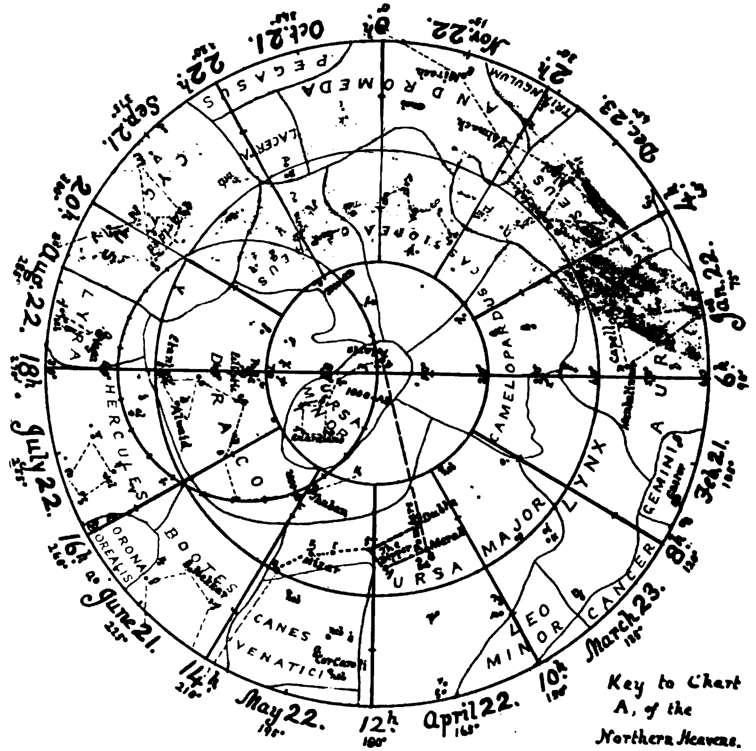
"What the name of the play is, no one knows. If there sits a spectator who knows, he sits so high that the players in the gaslight cannot hear his breathing."

George Sterling, in his immortal "Testimony of the Suns," says :

"So dreamt thy sons on worlds destroyed,
Whose dust allures our careless eyes,
As, lit at last on alien skies,
The meteor melts athwart the void.

"So shall thy seed on worlds to be,
At altars built to suns afar,
Crave from the silence of the star
Solution of thy mystery.

"And crave unanswered, till, denied
By cosmic gloom and stellar glare,
The brains are dust that bore the prayer,
And dust the yearning lips that cried."



Key to Chart A, of the Northern Heavens.


Oct. 21
Nov. 21
Dec. 21
Jan. 22
Feb. 21
March 21
April 22
May 22
June 21
July 22
Aug. 21
Sep. 21
CHART A.
The Northern Heavens.

CHAPTER XXIV

SIZE, IMPORTANCE, SPEED, AND DURATION

SIZE AND IMPORTANCE RELATIVE

"The appearance of things depends altogether on the point of view we occupy. He who is immersed in the turmoil of a crowded city sees nothing but the acts of men. . . . But he who ascends to a sufficient elevation . . . discovers that the importance of individual action is diminishing as the panorama beneath him is extending. And if he could attain to the truly philosophical, the general point of view, . . . rising high enough to see the whole world at a glance, his acutest vision would fail to discover the slightest indication of man, his free will, or his works. In her resistless onward sweep, in the clock-like precision of her daily and nightly revolution, in the well-known pictured forms of her continents and seas, now no longer dark and doubtful, but shedding forth a planetary light, well might he ask what had become of all the aspirations and anxieties, the pleasure and agony of life. As the voluntary vanished from his sight, and the irresistible remained, well might he incline to question . . . whether beneath the vastness, energy, and immutable course of a moving world there lay concealed the feebleness and imbecility of man. Yet it is none the less true that these contradictory conditions co-exist — *Free-will* and *Fate*, *Uncertainty* and *Destiny*. It is only the point of view that has changed, but on that how much has depended."
— *Dr. J. W. Draper.*

THE human family is an ephemeral form of organic life entirely confined to one insignificant planet in an inconspicuous stellar system. And the still more ephemeral individuals composing it are generally cooped up in a small corner of this little planet. It is therefore very difficult for those who take an interest in cosmical affairs to get correct and undistorted ideas as to the relative sizes and importance of the objects composing the Universe. Nor is it easy for them to accept the teachings of Astronomy with regard to the enormous speed with which some of these objects move through space, or the immense duration of the heavenly bodies in general. It may not,

therefore, be out of place to conclude our bird's-eye examination of the Universe with a few words on these subjects.

Man is a very important personage — in his own estimation. As a general thing he is so wrapped up in the petty details of his own mundane existence, that he fails to realise his own insignificance, either in the Universe at large or in the little World on which he lives and moves and has his being.

Yet a man is only one out of some 1,400,000,000 of similar beings. And as knowledge and wisdom bring modesty, he who thinks himself better and more important than his fellows is generally of very little account.

The same is true of the entire living race. All the men, women, and children on Earth are but a handful to those who have gone before, and will come hereafter in the ages yet to come. Future generations will look back with pity on our boasted wisdom and knowledge, even as we do on the wisdom and knowledge of former times.

The human race, as a whole, believes itself to be the *raison d'être* of the Universe, — "the end and aim of all creation." Yet it is but a thing of yesterday, doomed to perish to-morrow and be forgotten. For millions of years the Earth spun around its reeling axis, and circled around its little twinkling star, in company with a crowd of other planets. It did all this without the presence of man, and it will continue to circle and spin when the human family has passed away, like a streak of morning cloud, into the infinite azure of the past.

Our World is a very mighty world — to us. How mighty it is, only those who have traversed its oceans and continents can truly realise.

Yet, compared with the rest of the Universe, it is very, very small.

So small is it that the mind cannot grasp the idea of its littleness.

It is as a single leaf, compared with all the leaves of the forest.

It is as a blade of grass that withereth away, compared with all the grasses of the World.

It is as a drop of water, compared with all the oceans and seas.

It is as a grain of sand, compared with a world of similar grains.

Our Sun is 1,250,000 times as large as our Earth, and contains 330,000 times as much matter.

Though it is more than 90,000,000 miles away, it is bright enough to make the electric light seem black by contrast.

It is hot enough to turn our entire Earth into fire-mist if it were dropped into it. It is powerful enough to keep the planet Neptune in bondage, although thirty times as far from it as our Earth.

Yet this mighty Sun of ours is only one out of millions of similar suns. It is only a star among a Universe of stars.

Space is endless — limitless — bottomless. It has no bounds, either visible or invisible. It is a sea without surface or bottom, an ocean without a shore. And our telescopes and spectroscopes show that, all around us in the depths of this shoreless ocean, living suns like ours are strewed in hundreds of millions, while nebulæ and dead suns exist beyond all computation.

SPEED IS RELATIVE

When we hear that our World goes around the Sun at the speed of 18½ miles in a second of time, and that the Solar System itself is speeding toward the constellation of Lyra at the rate of 12½ miles per second, we naturally compare such motions with the rush of a bullet or cannon-ball. The result of the comparison is that the statements appear almost unbelievable. But if we change the comparison, and note that the Earth is seven minutes in moving the length of her own diam-

eter, and that the Sun is 16 hours in doing the same thing, the celestial velocities seem very moderate. The first comparison calls to mind the sharp "ping" of an invisible projectile. The second reminds one of the stately and almost imperceptible drift of a family of icebergs through the arctic seas.

In this case the figures do not become smaller, but the standpoint is changed, and that makes a wonderful difference in the result.

It is true that astronomy shows us instances of extremely small bodies travelling at even greater speed than the large ones. But in these cases it will be found that the small bodies are not moving by any energy of their own, or by any initial force that soon ceases to act. They are under the continuous influence of some celestial giant whose power is almost immeasurably great. The energy exerted is not merely initial but continuous and cumulative. The push or pull is therefore unimaginably vast, compared with any force that man can bring to bear on such an object. This being the case, it is quite natural and reasonable that the resulting motions should be almost beyond his comprehension and belief.

DURATION IS RELATIVE

"A generation passeth away,
And a generation cometh,
But the Earth abideth
For ages of ages. — *Eccles.* i, 4 (A. Zazel).

"But yestermorn, O boastful clay,
Thy planet from its parent broke —
O, insect of a summer's day,
Thy vaunted glories pass like smoke!" — *George N. Lowe.*

To some low forms of animal life a day represents an entire lifetime. In one day an entire generation is born, flourishes, and dies.[1]

[1] In some of the single-celled monera the average life of an individual is about four minutes, so that there are 360 generations in a day of 24 hours. One of our days is therefore equal to 12,000 years with them.

Yet, to a man, a day seems a very short period of time — that gets still shorter as he advances in years.

To a youth who is just entering into life, seventy years seem to make an almost endless stretch of time. There appear to be hardly any limits to what may be accomplished in threescore-and-ten long, long years.

But to the old man that life is little more than a dream — of high hopes unfulfilled — of noble aspirations that have been abandoned — of great expectations that have come to nought — of tardy realisations that have turned to ashes in the mouth.

In the lifetime of one individual many events take place among men, many changes occur in the World on which he lives.

Yet all the world-wide occurrences during such a lifetime form but a page of that history which — in Egypt and elsewhere — goes back more than 6,000 years.

Six thousand years of human activities almost becloud the mind. Through the mists of antiquity the early actors loom vague and vast. To the unenlightened they seem as Gods who wield the thunderbolt, control the tempest, and forge the chains of human destiny.

Yet 6,000 years form but a fragment of the history of man as revealed by the study of his remains. The human family is very, very ancient. So ancient indeed is it that many people refuse to accept the evidence they cannot overthrow.

If we assume that 6,000 generations of men have lived on this Earth — and the time cannot have been much less than that — we are utterly bewildered when we endeavour to realise such an abyss of time.

Yet such an interval is but a watch in the night when we compare it with the vast geological periods intervening between the dawn of life on Earth and the days when man first stood erect on *terra firma*. It must have taken millions of years to deposit the Carboniferous rocks alone, and they represent but a small fragment of geologic time.

Before the dawn of life on this globe there was a period during which the first gaseous and then molten Earth was but "a bare lurid ball in the vast wilds of space." During fathomless ages it slowly cooled off, till at last the surface became solid, and the vaporous ocean above was no longer kept off the blistering surface.

How long that period lasted we are utterly ignorant. For all we know it may have exceeded geological times as geological times exceeded the era of man.

Before the Earth was born — as a gaseous centre of condensation in a swirling mist, subsequently to shrink into a fiery globe — was a long, long period, during which a vast and shapeless nebula turned into a flat and symmetrical indrawing spiral.

And before that shapeless nebula *was*, the Universe *is*.

As R. A. Proctor says:

"The whole duration of this Earth's existence is but as a single pulsation in the mighty life of the Universe. Nay, the duration of the Solar System is scarcely more. Countless other such systems have passed through all their stages, and have died out, untold ages before the Sun and his family began to be formed out of their mighty nebula; countless others will come into being after the life has departed from our system. Nor need we stop at solar systems, since within the infinite Universe, without beginning and without end, not suns only, but systems of suns, galaxies of such systems, to higher and higher orders endlessly, have long since passed through all the stages of their existence as systems, or have all these stages yet to pass through."

It appears certain that matter and energy always existed and always will exist. They were never created and will never be destroyed. We have reason to believe that through all time the Universe contains exactly the same number of corpuscles, the same amount of energy. Suns and worlds come and go, like bubbles, on the River of Eternity. But the matter of which they are composed endures for ever and ever. The energy they contain neither waxes nor wanes. The one and the other are eternal — everlasting — imperishable. Science

teaches us that though the heavens change and the worlds decay, neither a corpuscle of matter nor an iota of energy will ever cease to exist.

SUMMARY

We thus see that size, importance, speed, and duration are all relative terms, denoting attributes that are either great or small according to the standpoint from which they are viewed.

The object of this work is to enable us to view all subjects from as many different standpoints as possible, so that we may not be deceived in the conclusions at which we arrive, about the Universe in general and our World in particular; about the human race as a grand total, and an individual as a minute fraction of it; about Eternity as a limitless whole, and our Earth-measured years as microscopic parts thereof.

CHAPTER XXV

CONCLUSION

"An undevout astronomer is mad." — *E. Young.*

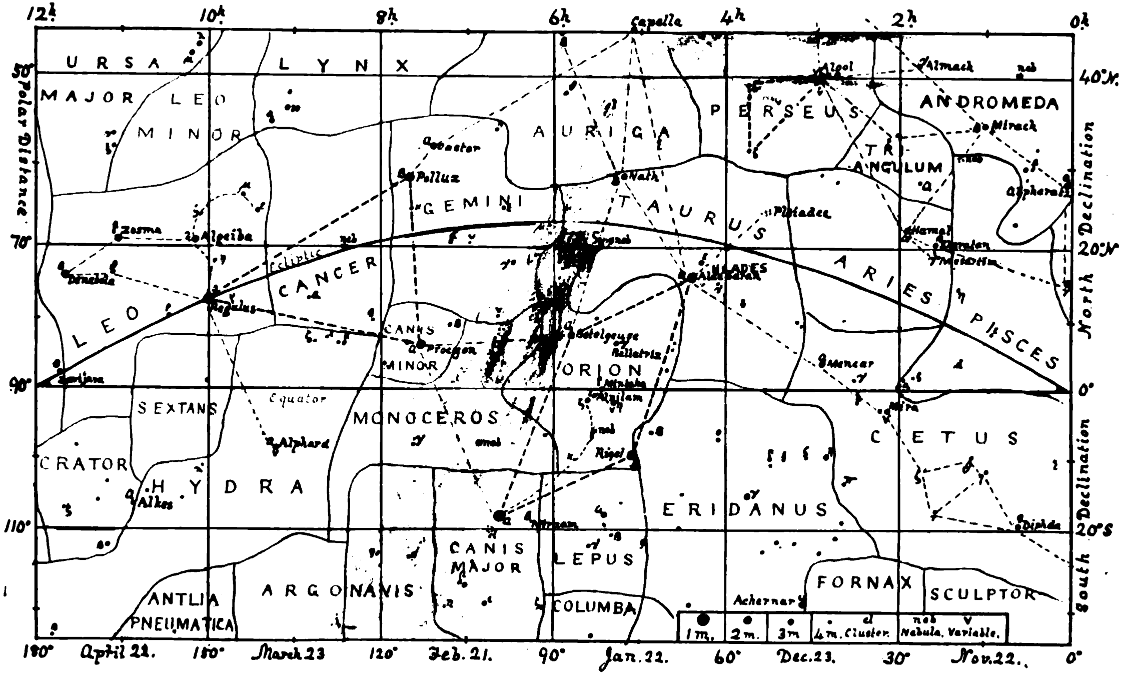
"Most of the religions of the world are more or less derived from Astronomy in its astrological childhood. The majority of their deities were once identified with the sun, moon, planets, or stars. Their temples, vestments, feasts, fasts, ceremonies, and writings, contain multitudes of celestial fossils which only astronomers can recognise and explain." — *A. Zazel.*

"It is Astronomy which will eventually be the chief educator and emancipator of the race." — *Sir Edwin Arnold.*

I HAVE now finished an account that is little more than a bare outline of what Science has to say about the Universe. Is it not a wonderful story, even when poorly told? Is it not a sublime picture, though seen as through a glass, darkly?

The astronomer of to-day is a cosmopolitan in the widest sense of the word. He is a citizen of the Great Cosmos — a traveller on the Ocean of Space — an explorer of what was but yesterday an unknown Universe. Though he is physically a prisoner on Earth, he is mentally free to roam through all the mansions of the skies. Though he is but one of a multitude of world-mites, he is the privileged spectator of the greatest of all the dramas. Though he is but an ephemeron, he can watch the mystic whirling of the myriad worlds through endless time and space. In the grandest of all temples he can hear the sublime "music of the spheres" echoing for ever through the lofty aisles. From his celestial watch-towers he surveys the wonders of "the house not made with hands, eternal in the heavens." He stands before the INFINITE; he contemplates the ETERNAL.

The human race owes much more to astronomy and its kindred sciences than it is aware of. All the production, transportation,



Key to Chart B. — Equatorial Constellations. For Spring Evenings.

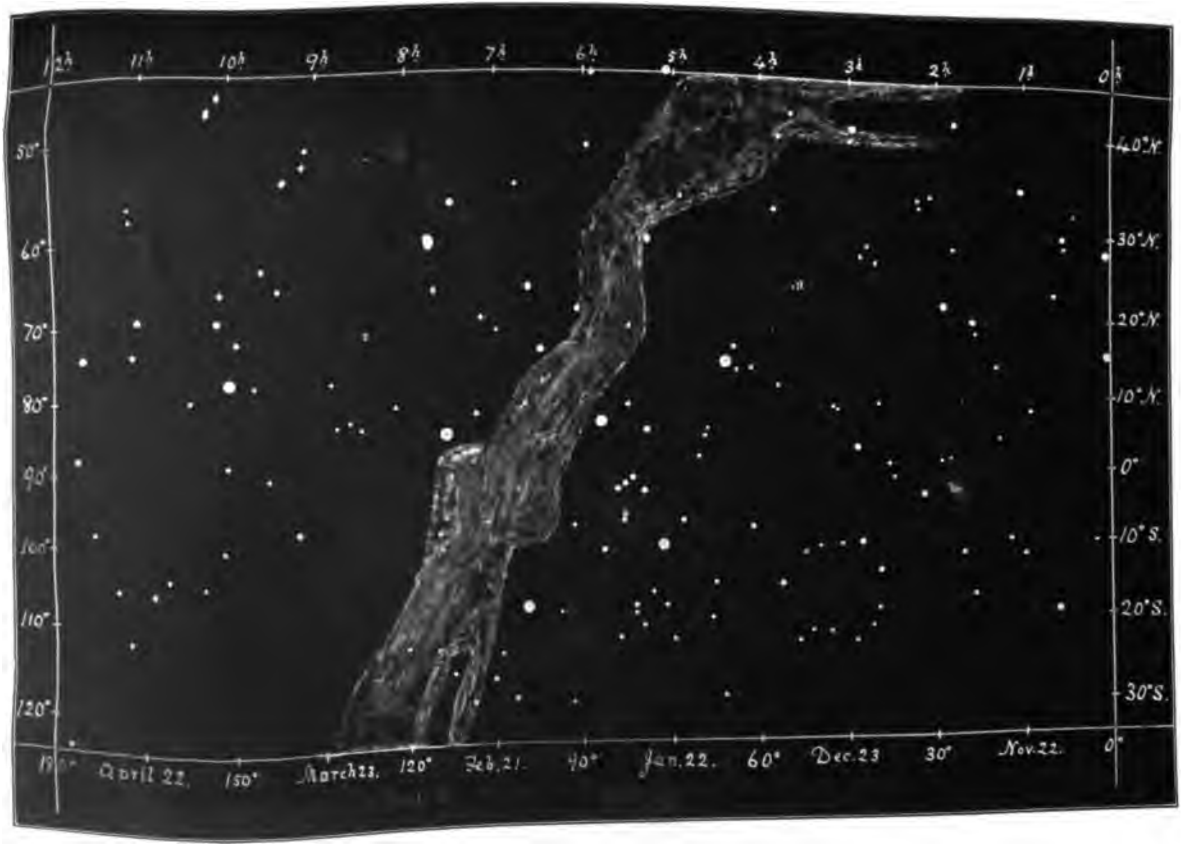


CHART B. — THE EQUATORIAL CONSTELLATIONS. FOR SPRING EVENINGS.

and distribution of the necessaries of life are regulated by the clock of the astronomer. Every train that crosses the continents with speed and safety does it through his observations. Every ship that crosses the otherwise trackless oceans is guided to port by his instruments and calculations. His predictions of astronomical phenomena are published in the "Nautical Almanac" several years before they occur, so that navigators may be able to correct the errors of their chronometers in whatever part of the World they may happen to be.

A single mistake in these predictions may bring death and disaster in any part of the globe. An improved method of calculation or observation may bring increased speed, certainty, and safety to the commerce of all the World.

The science of human history is largely indebted to astronomy for the correction of its dates. For some of the eclipses, comets, etc., which are mentioned in ancient documents and traditions, have been identified by calculating back, and the exact dates have been ascertained. When these have once been fixed, all the neighbouring dates can be adjusted to those which have been ascertained astronomically.

Some departments of science appear, at first sight, to be practically useless, because they have, or appear to have, no direct bearing on the welfare of the race. Yet even these bring indirect benefits which are too vast to be easily realised. *Pure science* can be cultivated only for itself, but it forms the foundation on which all *practical science* is based. Then the lessons that science teaches, on the art of getting at the truth, are as valuable as its most practical discoveries and practicable inventions. This is especially the case with astronomy. Even the necessary ills of life are lessened by a knowledge of the heavens, for in the presence of the illimitable and eternal Universe it seems absurd to worry about the little earthly troubles that we cannot remedy. We learn to accept the inevitable and make the best of it.

It may indeed be truthfully said that a fair knowledge of astronomy and geology will double the pleasures of life and

halve its troubles. At the same time it will entirely remove the creed-made terrors of death.

There are not many of us who can do much toward gaining fresh knowledge of the secrets of Nature. But there is no reason why we should not enlighten, broaden, and refresh ourselves by taking an interest in the scientific discoveries which are revolutionising the world and revealing the Universe to man.

The study of the Universe will not only make us enlightened citizens of the Great Cosmos, but will also make us better citizens of our own World. It will do this by teaching us to observe correctly the surrounding social and economic phenomena, instead of blindly trusting to the assertions of prejudiced and perhaps interested persons. It will also train us to reason correctly and impartially as to the causes and effects of the observed phenomena. We find ourselves, at the commencement of the twentieth century, confronted by serious industrial, economic, and social problems which demand solution at our hands. These problems are largely the result of scientific instruments of production and distribution, invented and developed during the last two centuries. We cannot solve these problems satisfactorily and equitably till we recognise the fact that human progress is subject to evolution — that it is in fact ruled by natural laws just as inexorable as those which govern suns and worlds. It is therefore necessary for us to ascertain what these laws are, and then to solve our industrial and social problems in accordance with them. When this is done, our wonderful advance in the arts and sciences will be paralleled by as rapid an advance toward universal prosperity and happiness. But not before.

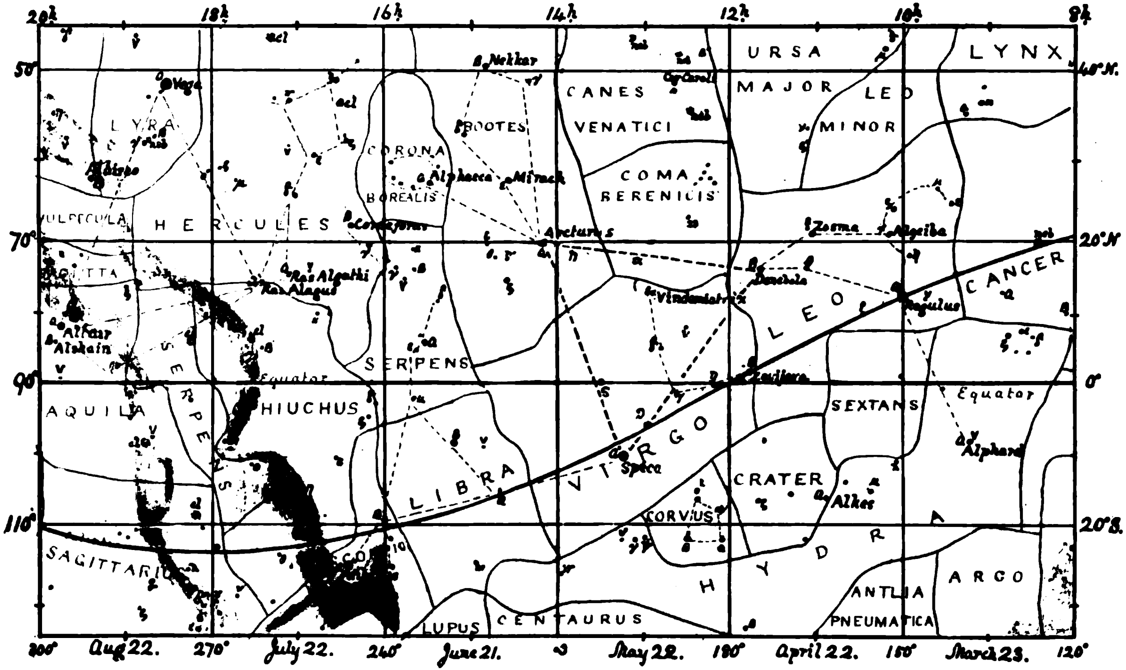
NOTE. — Those who wish to continue the study of the starry heavens will do well to get the popular works of Airy, Ball, and Serviss; also Comstock's "Text-book of Astronomy," which, at its close, gives a list of some of the best works on astronomy, both general and special.

ASTRONOMY

By George N. Lowe

(*By permission*)

Great Antidote for ignorance and fears,
We look to thee to lead us to the day.
Before thy light the darkness melts away —
Thy ceaseless labour Life's great pathway clears.
The shackles fall as pass the stately years,
Thy gaze uplifts, lo! Vega's distant day
Comes, captive, where thy mystic colours play —
The sombre gloom of ages disappears.
What though the thrones of false gods shake and fall,
Though useless, hoary, man-made creeds may fade?
Calm Reason knows no sorrow, reck, or ruth.
Thy touch, Boon Science, liberates the thrall;
Thy broadening beam illumes the unknown shade;
Patient, thy finger pointeth to the Truth.



Key to Chart C.—Equatorial Constellations. For Summer Evenings.

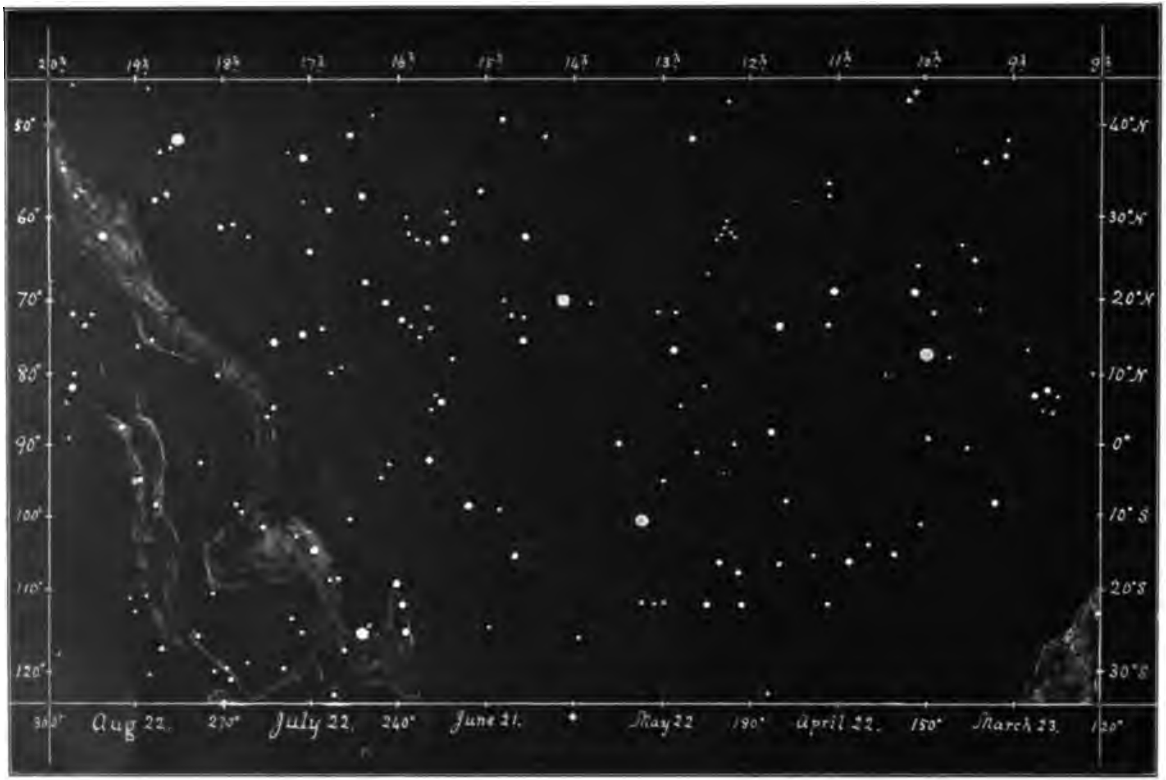


Chart C. — The Equatorial Constellations. For Summer Evenings.

APPENDIX A

FACTS AND FANCIES CONCERNING MATTER

"What is Matter? Never mind.
What is Mind? No matter."— *Old Queries.*

"What is Matter? Only a cloud of Corpuscles.
What are Corpuscles? Only Electricity.
What is Electricity? Only Matter.
What are they all? No matter. Never mind!"— *New Queries.*

ONLY A ROCK

TAKE up a small rock in your hand and examine it carefully with the naked eye.

It appears to consist of a number of irregular granules, differing in size and shape, but alike in colour and texture. It is only a piece of rock, rough, heavy, more or less hard and compact, and altogether insignificant.

Such a rock might serve a teamster very well to throw at his off leader, or a small boy might use it as a nucleus for a vicious snow-ball, but otherwise it is of no value to man or beast.

TWO STANDPOINTS

Yet these ideas concerning its insignificance are all owing to the fact that we view it from a human standpoint, without even the aid of science.

If we could examine it from the standpoint of one who possessed the all-seeing eye popularly attributed to some of the Gods, we should perhaps come to very different conclusions concerning its size, condition, and importance.

In order to do this, we shall have to increase our powers of vision and analysis by resorting to the microscope and other scientific instruments.

A MAGNIFIED ROCK

On applying a powerful magnifying-glass to the rock, we find that it no longer appears small and insignificant. In fact it is now so large that we can examine only a small part of it at once.

Its granulated surface has swelled into rugged rock-masses divided by narrow gulches and clefts. The surface of these masses of rock has the same granulated appearance that the whole rock had to the naked eye.

We will now select the smallest visible speck, and examine it with the microscope. The result is that the speck, which was almost invisible with the single magnifying-glass, is now a huge mass of rocky hills separated by gloomy gorges.

On closely observing the rocks which compose these hills, we see that the whole mass is honeycombed with crevices which were invisible before. Each mighty rock is seen to be composed of small granules loosely connected together.

A WORLD IN ITSELF

By vastly increasing the power of our microscope the hills become mountain-chains whose lofty peaks extend away into the remote distance. The stone which could be held in the hand has become a world in itself, shutting out the firmament from view.

Again and again we select the smallest visible granule, and subject it to examination with higher magnifying power. Each time we do so the almost invisible particle selected swells into an enormous mass that fills the field of view. Each successive particle is seen to consist of hills and gorges of more or less solid rock, composed of scarcely visible granules. But the substance of these granules is still the same as that composing the whole rock.

The magnifying powers of the most powerful microscope in existence are at last exhausted. We have to continue our examination by means of the spectroscope and other instruments, and view the results of our investigations with the eye of the imagination.

Confining ourselves to the smallest sub-granule revealed by the most powerful microscope, we see it gradually unfold itself as the magnifying power of the imagination is applied to it. When it becomes too large for minute examination, we select an almost invisible particle of it, and watch it grow till it fills the entire field of view. Again and again we do the same thing, each successive particle getting too large for inspection as it swells under the scrutiny of the scientific imagination.

As this process goes on, we notice a progressive change, not in the substance, but in the structure of what we are examining. It slowly loses its original solid appearance and becomes a dense nebulous haze.

MOLECULES

This haze gradually opens out, and finally resolves itself into a universe of small separate bodies which are commonly known as *molecules.* These appear to float in empty space without touching one another.

ATOMS

As the magnifying power of our imagination goes on increasing, each molecule is seen to be a group of shining *atoms,* clinging together in "radical" bunches, yet avoiding actual contact. These atoms are altogether different in appearance and properties from the molecules which they compose. They may be sorted out into several different species, the individual atoms of each kind being all absolutely alike, but different in size, weight, and other particulars from those of the other species.

CAPTIVE CORPUSCLES

The question now arises, What are these different kinds of atoms which constitute the molecules of which our rock is

built up? Are they single and indivisible, independent and unrelated, or are they, too, composed of still smaller particles?

In order to decide this question we pick out a single atom in one of the molecules and confine our attention to it exclusively. At the same time we once more increase the separating power of the imagination.

The atom now loses its indivisible character and is seen to consist of a star-cluster of minute *corpuscles*. These appear to have a regular orbital motion, at planetary distances, around their centre of gravity. They are kept together, and yet separate, by a combination of forces which is not yet understood.

These sub-elementary corpuscles are all identical in form, weight, and attributes. The only suspicion of difference is that they act as though one half of them were positively, and the other half negatively, electrified. They seem to cling together in pairs and form alternate layers around the centre of the cluster, the layers being far apart and sparsely occupied.

We now leave the atom we have just resolved into corpuscles, and devote our attention to the other species of atoms which build up the molecules of matter. They are all resolvable into star-clusters of corpuscles which are exactly the same as those which composed the atom first examined. The only difference appears to be in the number and arrangement of the corpuscles which compose the different kinds of atoms. The smallest known atoms contain about a thousand corpuscles.

The outside layer of corpuscles in an atom appears to be always composed of negatively electrified corpuscles, some of which have the power of flitting from one atom to another, and of flying off into space as free and independent corpuscles.

FREE CORPUSCLES

Besides the corpuscles which go to build up the various atoms, there is an immense multitude of negatively electrified corpuscles which exist in a free state. The atoms of matter

move through this "dust-cloud" of free corpuscles as readily as a sieve moves through water without displacing it. The otherwise unoccupied space between the atoms of matter is filled to saturation with these free negative particles, which carry the vibrations of ponderable matter from one atom to another. They form the *luminiferous ether* which fills all space.

ULTIMATE PARTICLES

We now seem to have at last reached a stage where all matter is identical in substance, form, weight, appearance, and properties. The ultimate particles of which matter is composed appear to be revealed to the eyes of the imagination. But we are still entirely in the dark as to the nature of these ultimate and identical particles, and the reason why they group themselves as they do, to build up the atoms and molecules of ponderable matter. We are now face to face with the unsolved Riddle of the Universe. We are dealing with the mysterious astronomy of the atoms. We have found the simple bricks out of which the elaborate structures of the Universe are built, but cannot tell whence, nor why, nor what they are. Even the imagination has at last reached the limit of its power, and we are hopelessly lost in trying to solve the great Problem of Substance.

A TINY UNIVERSE

Now, for all we know to the contrary, the nebulous cloud of matter we have been examining may be a Universe like ours. Its molecules may be aggregations of atomic star-clusters like those revealed by the telescope. Its electrical corpuscles may be suns like ours, sending forth their radiant energy to invisible worlds, some of which may be inhabited by unreasoning creatures like man.

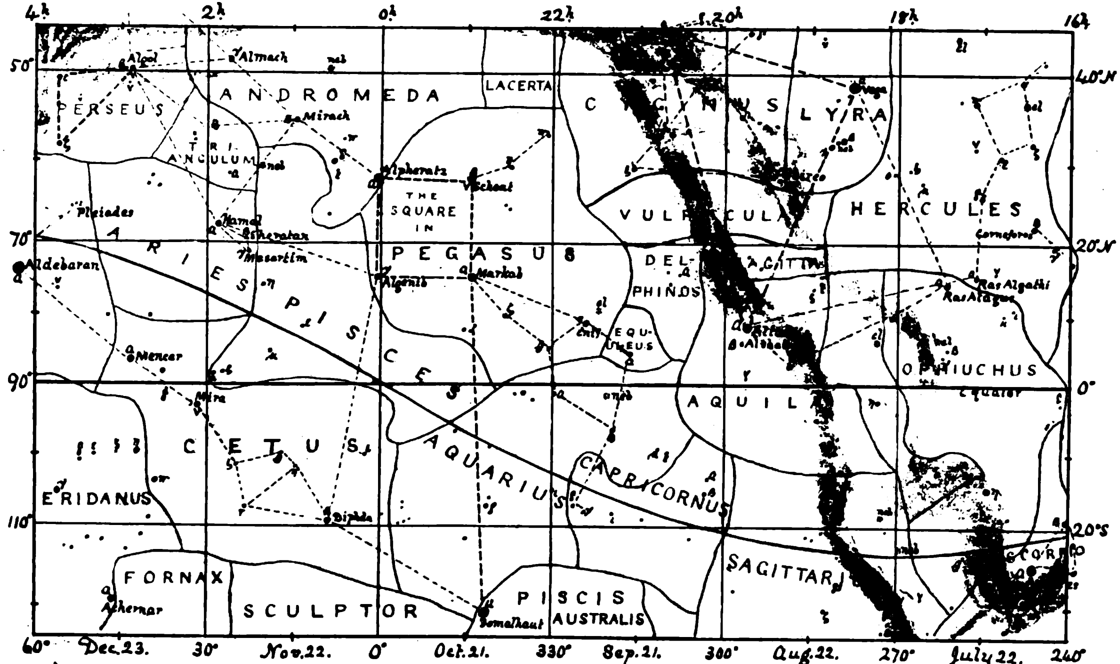
If such should be the case (and it would not be very easy to disprove it), then an inhabitant of one of these invisible worlds probably thinks that his Earth is the only one in existence;

that he is the one for whom all things were created; that his eternal well-being is the chief concern of the Creator; and that his moment of life is a big part of Eternity.

So much for the rock we have been studying. Let us now throw it away and turn our attention to some of the more pressing problems of lunar politics.

WHO KNOWS?

Yet before doing so I would like to ask, How do you know that our mighty Universe is not a similar pebble on the shore of some gigantic world? It may seem to some that absurdity could go no further than this suggestion. Yet it is a surmise logically based on the generally accepted infra-atomic "star-clusters" of our foremost scientists. As such I cheerfully submit it to them for their prayerful consideration. If their corpuscular theory of atoms is true — and I should be the last to deny it — then this celestial application of it may be true also. Or it may not. *¿ Quien sabe?*



KEY TO CHART D. — EQUATORIAL CONSTELLATIONS. FOR AUTUMN EVENINGS.

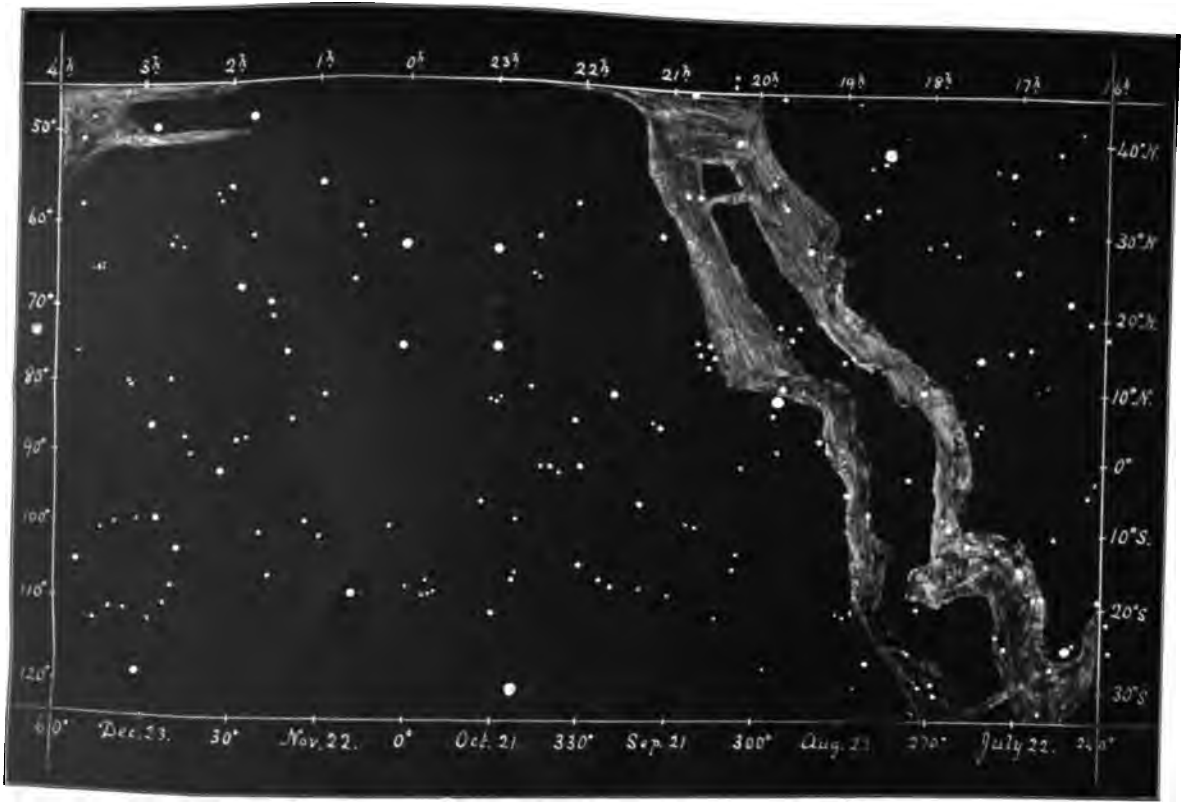


Chart D. — The Equatorial Constellations. For Winter Evenings.

APPENDIX B

THE GREEK ALPHABET

THE study of the Star Charts requires a knowledge of the Greek alphabet. It is therefore printed here for reference, with the name and sound of each letter.

Greek		Name	English
Α	α	Alpha	a
Β	β	Beta	b
Γ	γ	Gamma	g
Δ	δ	Delta	d
Ε	ε or ϵ	Epsilon	ĕ
Ζ	ζ	Zeta	z
Η	η	Eta	ē
Θ	ϑ or θ	Theta	th
Ι	ι	Iota	i
Κ	κ	Kappa	k
Λ	λ	Lambda	l
Μ	μ	Mu	m
Ν	ν	Nu	n
Ξ	ξ	Xi	x
Ο	ο	Omicron	ŏ
Π	π	Pi	p
Ρ	ρ	Rho	r
Σ	σ or ς	Sigma	s
Τ	τ	Tau	t
Υ	υ	Upsilon	u
Φ	φ	Phi	ph
Χ	χ	Chi	ch
Ψ	ψ	Psi	ps
Ω	ω	Omega	ō

APPENDIX C

THE LUNAR CRATERS

Explanation of the First Four Tables

THE number before the name of a crater indicates its place on the charts.

The craters which have no number before them are lettered on the charts.

Small odd numbers (1 to 81) indicate craters on the *north* half of the *western* chart.

Large odd numbers (83 to 169) indicate craters on the *south* half of the *western* chart.

Small even numbers (2 to 68) indicate craters on the *north* half of the *eastern* chart.

Large even numbers (70 to 176) indicate craters on the *south* half of the *eastern* chart.

The names in *italics* indicate craters near the *centre* of the lunar disc.

The names in roman type indicate craters near the *circumference* of the lunar disc.

Small numbers in parentheses, ( ), denote the diameter of the crater *in miles.*

Large numbers in brackets, [ ], denote the extreme height of the rampart (*in feet*) above the floor of the crater.

TABLE I

Craters on the Northwest Quarter of the Moon

[*See Chart F*]

1 Barrow (40)
3 Strabo
5 Aristoteles (60), [11,000]
7 Endymion (80)
9 Atlas (55), [11,000]
11 Hercules (46), [11,000]
13 Berg
15 Eudoxus (40)

17 Messala
19 Cassini (36), [4,000]
21 Gauss (110)
23 Berzelius
25 Theætetus
27 Geminus
29 Aristillus (34), [11,000]
Posidonius (60), [6,000]
31 *Autolycus* (23), [4,000]
33 *Linné*
35 Burckhardt
37 Tralles
39 Cleomenes (80), [10,000]
41 Roemer
43 Macrobius (40), [13,000]
45 *Bessel*
47 Maraldi
49 *Sulpicius Gallus*
51 Peirce
53 Vitruvius
Proclus
55 Alhazen
57 Dawes
Menelaus (20)
59 Hansen
61 Picard
Plinius (30), [6,000]
Manilius (25)
63 Condorcet
65 *Julius Cæsar*
67 Firmicus
69 Taruntius
71 *Silberschlag*
73 *Hyginus*
75 *Ariadæus*
77 *Agrippa* (30)
79 *Triesnecker* (20)
81 *Godin* (22)

TABLE II

Craters on the Southwest Quarter of the Moon

[*See Chart F*]

83 Webb
85 Messier
87 *Delambre*
89 *Hipparchus* (100)
91 *Hypatia*
93 Langrenus (90), [10,000]
95 *Torricelli*
97 *Taylor*
99 Isadorus
101 Guttemberg (45)
103 Goclenius (28)
Theophilus (64), [18,000]
105 *Cyrillus* (60)
107 *Albategnius* (65), [15,000]
109 *Abulfeda*
111 Vendelinus
113 Catharina (65)
115 *Almamon*
117 *Sacrobosco*
119 Santbeck
121 Fracastorius
123 *Apianus*
125 Humboldt [16,000]
Petavius (78)
127 Pontanus
129 *Werner* (45)
131 *Aliacensis* [16,000]
133 Piccolomini [15,000]
135 Zagut
137 Reichenbach
139 Walter (100)
141 Lindenau
143 Gemma
145 Frisius
147 Neander
149 Rabbi Levi

151 Stiborius
153 Furnerius
155 Rheita
157 Maurolycus (150), [14,000]
159 Stöfler (110)
161 Fabricius
163 Clairaut
165 Pitiscus
167 Bacon
169 Curtius

TABLE III

Craters on the Northeast Quarter of the Moon

[*See Chart E*]

2 Philolaus
4 Pythagoras
6 Fontanelle
8 Condamine
Plato (60), [7,000]
10 Harpalus
12 Bianchini
14 Sharp
16 Leverrier
18 Helicon
20 Mairan
22 Herschel (17)
24 Gruithuisen
26 Lichtenberg
Archimedes (52), [4,000]
28 Delisle
30 *Beer*
32 *Timocharis* (23), [7,000]
34 Diophantus
36 Lambert (17)
38 Euler (19)
Aristarchus (28)
40 Herodotus
42 *Pytheas*
44 Tobias Mayer
46 *Eratosthenes* (37), [16,000]
48 Bessarion
50 Marius
52 *Stadius*
Copernicus (56), [12,000]
54 Galileo
Kepler (22)
56 Reiner
58 *Schroeter*
60 *Reinhold*
62 Kunowsky
64 Encke
66 Hevel
68 *Gambert*

TABLE IV

Craters on the Southeast Quarter of the Moon

[*See Chart E*]

70 *Landsberg*
72 *Mosting*
74 *Lalande*
76 *Fra Mauro*
78 *Parry*
80 *Bonpland*

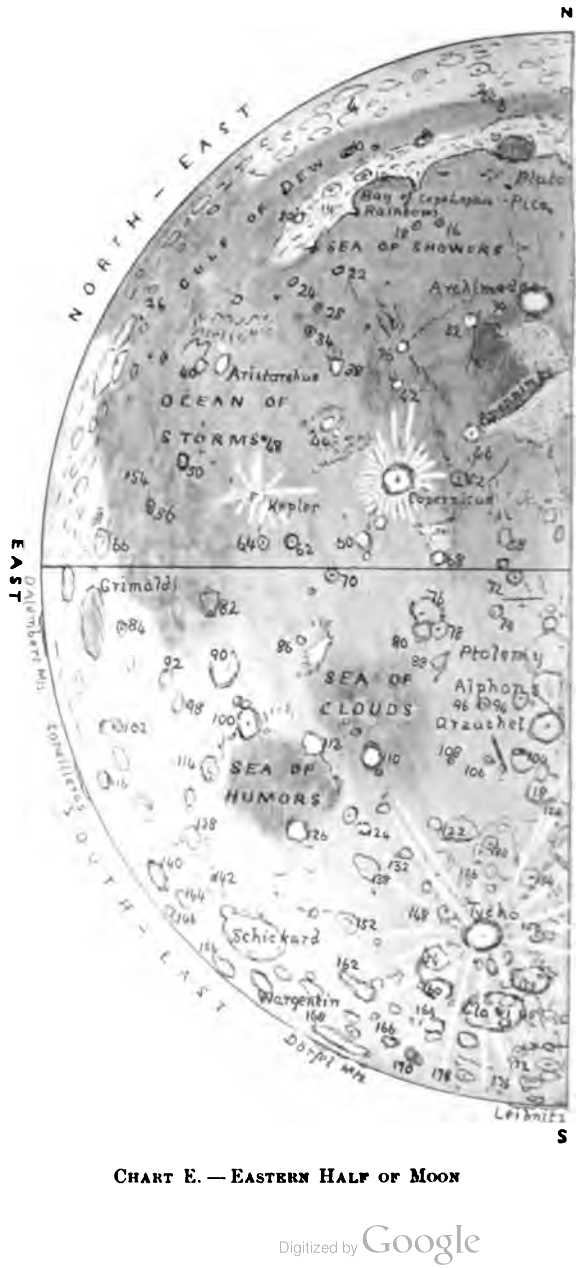


Chart E. — Eastern Half of Moon

Chart F. — Western Half of Moon

82 Flamsteed
84 Damoiseau
Grimaldi (150)
86 Euclides
Ptolemy (115)
88 *Guerike*
90 Letronne
92 Hansteen
Alphons (83)
94 *Alpetragius*
96 *Lassell*
98 Billy
Arzachel (65)
100 Gassendi (54)
102 Fontana
104 *Thebit* (30)
106 *Birt*
108 *Nicollet*
110 *Bullialdus* (38), [8,000]
112 Agatharchides
114 Mersenius (40)
116 Eichstadt
118 *Purbach* (60)
120 *Regiomontanus*
122 Pilatus
124 Mercator
126 Vitello (24)
128 Vieta
130 Hell
132 Cichus
134 Lexell
136 Ball
138 Capuanus
140 Lagrange
142 Lacroix
144 Piazzi
146 Bouvard
148 Heinsius
150 Saussure
Tycho (54), [17,000]
152 Hainzel
Schickard (134), [9,000]
154 Wilhelm I.
156 Inghirami
158 Maginus (100)
Wargentin (53)
160 Longimontanus
162 Schiller
Clavius (140), [17,000]
164 Scheiner
166 Bettinus
168 Bailly
170 Kircher
172 Moretus
174 Casatus
176 Newton [24,000]

TABLE V

Alphabetical List of Craters

Abulfeda, 109
Agatharchides, 112
Agrippa, 77
Albategnius, 107
Alhazen, 55
Aliacensis, 131
Almamon, 115
Alpetragius, 94
Alphons
Apianus, 123
Archimedes
Ariadæus, 75

Aristarchus
Aristillus, 29
Aristoteles, 5
Arzachel
Atlas, 9
Autolycus, 31

Bacon, 167
Bailly, 168
Ball, 136
Barrow, 1
Beer, 30

Berzelius, 23
Bessarion, 48
Bessel, 45
Bettinus, 166
Bianchini, 12
Billy, 98
Birt, 106
Bonpland, 80
Bouvard, 146
Bullialdus, 110
Burckhardt, 35
Burg, 13

Capuanus, 138
Casatus, 174
Cassini, 19
Catharina, 113
Cichus, 132
Clairaut, 163
Clavius
Cleomenes, 39
Condamini, 8
Condorcet, 63
Copernicus
Curtius, 169
Cyrillus, 105

Damoiseau, 84
Dawes, 57
Delambre, 87
Delisle, 28
Diophantus, 34

Eichstadt, 116
Encke, 64
Endymion, 7
Eratosthenes, 46
Euclides, 86
Eudoxus, 15
Euler, 38

Fabricius, 161
Firmicus, 67
Flamsteed, 82
Fontana, 102
Fontanelle, 6
Fracastorius, 121
Fra Mauro, 76
Frisius, 145
Furnerius, 153

Galileo, 54
Gambert, 68
Gassendi, 100
Gauss, 21
Geminus, 27
Gemma, 143
Goclenius, 103
Godin, 81
Grimaldi
Gruithuisen, 24
Guerike, 88
Guttemberg, 101

Hainzel, 152
Hansen, 59
Hansteen, 92
Harpalus, 10
Heinsius, 148
Helicon, 18
Hell, 130
Hercules, 11
Herodotus, 40
Herschel, 22
Hevel, 66
Hipparchus, 89
Humboldt, 125
Hyginus, 73
Hypatia, 91

Inghirami, 156
Isadorus, 99

Julius Cæsar, 65

Kepler
Kircher, 170
Kunowsky, 62

Lacroix, 142
Lagrange, 140
Lalande, 74
Lambert, 36
Landsberg, 70
Langrenus, 93
Lassell, 96
Letronne, 90
Leverrier, 16
Lexell, 134
Lichtenberg, 26
Lindenau, 141
Linné, 33
Longimontanus, 160

Macrobius, 43
Maginus, 158
Mairan, 20
Manilius
Maraldi, 47
Marius, 50
Maurolycus, 157
Menelaus
Mercator, 124
Mersenius, 114

Messala, 17
Messier, 85
Moretus, 172
Mosting, 72

Neander, 147
Newton, 176
Nicollet, 108

Parry, 78
Peirce, 51
Petavius
Philolaus, 2
Piazzi, 144
Picard, 61
Piccolomini, 133
Pilatus, 122
Pitiscus, 165
Plato
Plinius
Pontanus, 127
Posidonius
Proclus
Ptolemy
Purbach, 118
Pythagoras, 4
Pytheas, 42

Rabbi Levi, 149
Regiomontanus, 120
Reichenbach, 137
Reiner, 56
Reinhold, 60
Rheita, 155
Roemer, 41.

Sacrobosco, 117
Santbeck, 119
Saussure, 150
Scheiner, 164
Schickard
Schiller, 162
Schroeter, 58
Sharp, 14
Silberschlag, 71
Stadius, 52
Stiborius, 151
Stöfler, 159
Strabo, 3
Sulpicius Gallus, 49.

Taruntius, 69
Taylor, 97
Theætetus, 25
Thebit, 104
Theophilus
Timocharis, 32
Tobias Mayer, 44
Torricelli, 95
Tralles, 37
Triesnecker, 79
Tycho

Vendelinus, 111
Vieta, 128
Vitello, 126
Vitruvius, 53
Walter, 139
Wargentin
Webb, 83
Werner, 129
Wilhelm I, 154

Zagut, 135

Chart G. — The Co

A Vie

Astrological Heav

to explain the

Persian, Jewish

Relig

Northern Hemisphere.

Translation.

Pôle Nord - -	**North Pole.**	**Ours; Sanglier; Ane; Typhon - -**	**Bear; Boar; Ass; Typhon.**
Voye Lactée -	**Milky Way.**	**Poissons - - -**	**Pisces — the Fishes.**
Hydre - - -	**Hydra.**	**Andromede -**	**Andromeda.**
Taureau - -	**Taurus; Bull.**	**Dragon des Hesperides**	**Dragon of the Hesperides**
Orion; Nemrod -	**Orion; Nimrod.**	**Vierge; Eve; Sybille; Isis, &c.**	**Virgin; Eve; Sybil; Isis, &c.**
Gemeaus - -	**Gemini.**	**Bootes; Adam; Osiris;**	**Bootes; Adam; Osiris.**
Crab ou Cancer -	**Crab or Cancer**	**Couronne - -**	**Corona Borealis.**
Bellier; Agneau de Dieu	**Ram; Lamb of God; Aries.**	**Hercule - -**	**Hercules.**
Persée; Cherubin -	**Perseus; Cherubim.**	**Serpent d'Eve; Ahriman; Satan**	**Eve's Serpent; Ahrimanes; Serpentinus.**
Etable d'Iouseph	**Joseph's Stable; Auriga.**		
Lion - - -	**Lion; Leo.**		

STELLATION FIGURES.

of the
n of the Ancients
Iysteries of the
AND CHRISTIAN
IONS.

Southern Hemisphere.

Translation.

Chien; Sirius	Dog; Sirius.	Corbeau de Noé	Noah's Raven; Corvus
Eridan	Eridanus.	Verseau	Aquarius, the Water-bearer.
Baleine	Whale; Cetus.	Capricorne	Capricornus.
Nil	Nile.	Sagittaire	Sagittarius, the Archer
Coupe	Crab; Cup.	Voye Lactée	Milky Way.
Vaisseau; Argo; Arche	Vessel; Argo; Navis; Ark.	Scorpion	Scorpio.
Canopus	Canopus.	Balance	Scales; Libra.
Pôle Sud	South Pole.		

INDEX

Absorption of starlight, 84
Absorption spectra, 92
Airy, Sir George, 26, 39
Aldebaran, 103
Algol, 108
Allen, Dr. F. J., 273
Alpha Centauri, 53, 78
Alpha Draconis, 147
Alphonso, King, 20
Alt-azimuth telescope, 153
Andromeda, nebula in, 122
Angles, measurement of, 31, 39
Angular diameter, 41
Aphelion, 160
Apocalypse, 17, 26, 239
Apparent motions, 4
Appearances, superficial, 1
Aratus, 118
Arc, chord of, 41; of circle, 40
Arc problems, 47
Aries, First Point of, 10, 148
Aristarchus, lunar crater, 264
Aristotle, 163
Ascension, right, 149
Asteroids, 29, 61, 64
Astronomy, Egyptian, 16; Greek, 16, 42; Hindu, 23, 43
Atomic theory, 192
Autumnal equinox, 7, 139

Balance, torsion, 38
Base line, 31, 32, 34
Becquerel rays, 197
Bede, Venerable, 17
Beta Lyræ, 108
Bifrost, Bridge of, 87
Binaries, 108, 110
Blood discs, stack of, 73
Brahé, Tycho, 19
Bridge of Bifrost, 87
Byron, Lord, 188

Calcium flocculi, 136
"Canals" of Mars, 226
Cannon-ball, speed of, 71
Canopus, 104
Canopy theory, 16
Celestial distances, measurement of, 32
Celestial equator, 7, 119
Celestial latitude and longitude, 150
Chariot of imagination, 53, 136, 220
Chord of arc, 41
Chromosphere, or sierra, 60, 129
Circle, arc of, 40; meridian, 152
Clavius, lunar crater, 253
Clouds, Magellanic, 122
Clusters of stars, 111
Colliding stars, 110, 206, 237
Colours of stars, 98, 111
Comets, 221
Comparisons, planetary, 69, 77
Constellations, 115, 137
Copernican system, 24
Copernicus, lunar crater, 263
Corona, 60, 131, 176
Corpuscles, or negative particles, 89, 199
Craters, lunar, 245, 253, 254, 264
Creation, 18
Creationism, 180
Crookes, Sir William, 179, 196
Crystal spheres, 18

Dark stars, 107, 135
Darwin, Charles, 201
Darwin, George, 204, 213
Declination, north and south, 149
DeQuincey, Thomas, 77

Dipper, the, 14
Distances, estimating, 30; measurement of celestial, 32; measurement of inaccessible, 31, 43; of stars, 123
Distribution of stars and nebulæ, 114, 121
Diurnal motion, 4
Double stars, 108, 110; spectroscopic, 108
Draco, 117
Draper, Dr. John W., 22, 156, 178, 265, 283
Drift, solar, 111; stellar, 113, 147
Duffield, Prof., 174

Earth, 62, 69, 139; centre of system, 15; measuring the, 31; revolution of, 23, 138; rotation of, 23, 138; shape of, 3; weight of, 38
"Ecclesiastes," 286
Eclipses, 11, 146
Ecliptic, 8, 9, 119, 138
Egyptian astronomy, 16
Electro-magnetic theory, Maxwell's, 195
Electronic theory, 200
Elements, in sun, 129; periodic system of, 192
Ellipse, 158
Equator, celestial, 7, 119
Equatorial telescope, 12, 150
Equinoxes, 7, 139; precession of, 141, 174
Eros, 33
Estimating distances, 30
Ether, 89, 171, 191, 195
Evolution of organic life, 201, 274
Evolution of solar system, 208
Evolution, tidal, 202, 213

Faculæ and flocculi, 127, 130
"Faust," Goethe's, 63
"Faustus," Marlowe's, 21, 136
Fibre, quartz, 75
Firmament, massive, 15, 16
Flames, solar, 59, 130, 176
Flat-world ideas, 15
Fleming, Prof. J. A., 190
Flocculi and faculæ, 127, 130
Fraunhofer, Joseph von, 194

Galaxy, the, 56, 120
Galileo, 169, 258; his laws of motion, 164
"Genesis," 15, 82, 87
George, Henry, 155, 163
Goethe's "Faust," 63
Gravitation, law of, 167
Great Bear, 14, 120
Great Pyramid, 147
Greek astronomy, 16, 42

Haeckel, Ernst, 174, 207, 217
Helium, 197
Hercules, cluster in, 111
Herschel, Sir William, 185
Hindu astronomy, 23, 43
Holden, Dr. Edward S., 22
Human laws, 156

Inertia, 164

"Job," 17
Jupiter, 27, 64, 69, 233

Kant, Immanuel, 184
Kathode rays, 196
Keeler, Prof. James E., 122
Kepler, Johann, 258; Laws of, 157
Kinetic theory of substance, 194
Kirchhoff, Gustav R., 194
Koran, the, 17

Land-surveying, 31
Laplace, Pierre, 184
Latitude, celestial, 150
Lavoisier, Antoine L., 193
Law of gravitation, 167
Law of substance, 192
Laws, human, 156; of motion, 164; of nature, 155
Life, evolution of organic, 201, 274
Light, refraction of, 89; speed of, 54, 72
Light waves, lengthening of, 84; violet, 73, 91
Light years, 68

Line of sight, motion in, 100
Locomotive, speed of, 84
Lodge, Sir Oliver, 200
Longitude, celestial, 150
Lowe, Geo. N., 85, 156, 286, 293
Lunar craters, 245, 253, 263, 264
Lunar mountains, 260
Lunar plains, 245
Luther, Martin, 23
Lyre, constellation of, 112

MAGELLANIC CLOUDS, 122
Magnitude, stellar, 102, 103
Marlowe's "Faustus," 21, 136
Mars, 27, 63, 69; "canals" of, 226
Mass and weight, 36
Massive firmament, 15, 16
Matter, 89, 191, 295; pyknotic theory of, 195
Maunder, E. W., 118, 120
Maxwell's electro-magnetic theory, 195
Mayer, Robert, 193
Measurement, of angles, 31, 39; of celestial distances, 32; of inaccessible distances, 31, 43; of the earth, 31
Mercury, 27, 69
Meridian circle, 152
Meteorites, 220, 230
Meteors, 230
Midsummer solstice, 8
Milky Way, 56, 120
Millikan, R. A., 198
Milton, John, 53, 120, 223, 224, 243, 271
Mira Ceti, 108
Moon, the, 244; birth, 257; distance, 45; motions, 11, 23; size and mass, 35
Morris, George, 280
Motion, diurnal, 4; in line of sight, 100; laws of, 164; of sun, 6, 7
Motions, apparent, 4
Mural circle, 153

NADIR, 5
Nasmyth, James, 257
Nature, laws of, 155
Nebulæ, 121-123; classes of, 97; distribution of stars and, 114, 121; planetary, 97
Nebular hypothesis, 184, 207
Negative particles, 89, 199
Neptune, 66, 69
New stars, 109
Newcomb, Prof. Simon, 68, 77, 84, 114
Newton, Sir Isaac, 124, 162; his law of gravitation, 167
North and south declination, 149
Nutation, 175

OBLIQUITY OF ECLIPTIC, 8, 138
Organic life, evolution of, 201, 274
Orientation of pyramid, 147
Orion nebula, 123

PAPER, pile of, 72; roll of, 77
Parallax, 44
Particles, negative, 89, 199
Pascal, Blaise, 84
Passover, spring, 7, 139
Perihelion, 140, 160
Periodic system of elements, 192
Perturbations of planets, 171
Photographing stars, 83
Photosphere of sun, 59, 126
Planetary comparisons, 69, 77
Planetary nebulæ, 97
Planets, 3, 61, 211; comparative distances, 27, 33, 77; density, mass, and size, 35, 36; inferior and superior, 27, 28, 61; motions of, 11, 138; move in ellipses, 29, 157; order of, 26; perturbations of, 171; real distances of, 29, 33, 68
Plato, lunar crater, 263
Pleiades, the, 103, 120
Pointers, the, 14
Polaris, 14, 103, 111
Pole-stars, different, 141, 147
Poles of rotation, 140
Precession of equinoxes, 141, 174
Prisms, 87
Proctor, Richard A., 85, 118, 124, 125, 288
Prominences, solar, 59, 130, 176

"Psalms," the, 57
Ptolemaic system, 18
Ptolemy, 42, 118
Pyknotic theory of matter, 195
Pyramid, the Great, 147
Pythagoras, 23

Quartz fibre, 75

Radial motions, 100
Radian, 40
Radiant energy of sun, 133
Radiation, spectrum, 92
Radium, 198
Radius vector, 160
Railroad to Neptune, 71; to nearest star, 75
Rainbow, 87
Rays, Becquerel, 197; kathode, 196
Red light-waves, 91
Refraction of light, 89
Repulsion, 176
Reversing layer of sun, 129
Revolution of the earth, 23, 138
Revolving wheel, 75
Right Ascension, 149
Ring nebula in Lyra, 122
Röntgen rays, 196
Rotation, of the earth, 23, 138; of planets, 138, 209; of sun, 129; poles of, 140

Satellites, or Moons, 61, 62, 65
Saturn, 27, 64, 69
Schaeberli, Prof., 122
Schiaparelli, 266
"Seasons, The," 229
Seasons on the earth, 139
See, Dr. J. J., 84, 101
Serviss, Garrett P., 120
Shakespeare, 140
Shelley, Percy B., 57, 205
Shooting stars, 230
Sierra, or chromosphere, 60, 129
Sight, motion in line of, 100
Signs of zodiac, 10, 137
Sine of angle, 43
Sine problems, 49
Sirius, 68, 78, 103
Solar flames or prominences, 59, 130, 176
Solar system, drift of, 111; evolution of, 208
Solstice, midsummer, 8; winter, 140
Spectroscope, 88, 194
Spectroscopic binaries, 108
Spectrum, 88; continuous, 92; of nebulæ, 96; stellar, 95; of star-clusters, 96
Spectrum, absorption, 92
Spectrum analysis, 93
Spectrum, emission, or radiation, 92
Spectrum, flash, of sun, 129
Spencer, Herbert, 201
Spheres, crystal, 18; umbrella, 4
Spider's thread, 74
Spiral nebulæ, 98, 122
Spots in the sun, 127
Spring passover, 7, 139
Starlight, absorption of, 84
Stars, 3; beyond planets, 26; classes of, 98; clusters of, 111; colliding, 110, 206, 237; colours of, 98, 111; dark, 107, 135; distances of, 23; distribution of, 114, 121; double, 108, 110; drift of, 113, 147; magnitudes, 102, 103; nearest, 34, 68; new, 109; number of, 82; photographing, 83; telescopic, 83; trails, 13; variable, 107; visible, 55, 82
Steele, J. D., 167
Stellar drift, 113, 147
Sterling, George, 53, 84, 102, 109, 126, 205, 281, 282
Substance, law of, 192; theories of, 194, 195
Sun, annual motion, 7; bulk and mass, 37; chromosphere or sierra, 60, 129; corona, 60, 131, 176; daily motion, 6; diameter, 35; distance, 32; elements in, 129; faculæ and flocculi, 127, 130; flames, 59, 130, 176; interior, 125, 134; photosphere or visible surface, 59, 126; prominences or solar flames, 59, 130, 176; radiant energy, 133; reversing layer, 129; rotation, 129; spots, 127

Suns, colliding, 110, 206, 237
Superficial appearances, 1

Telescope mountings, alt-azimuth, 153; equatorial, 12, 150; meridian circle, 152; mural circle, 153; transit instrument, 153
Telescopic stars, 83
Tele-spectroscope, 95
Tennyson, Alfred, 110
"Testimony of the Suns," 53, 84, 102, 109, 126, 205, 281, 282
Theophilus, lunar crater, 253
Thomson, Prof., 196
Thomson, James, "The Seasons," 229
Thread, quartz, 75; spider's, 74; a strand of, 74
Tidal evolution, 202, 213
Time, difference in, 5, 12
Torsion balance, 38
Trails, star, 13
Transit instrument, 153
Triangulation, 31
Trifid Nebula, 123
Trigonometry, 39
Tycho Brahé, 19

Umbrella spheres, 4
Universes, outside, 86
Uranus, 66, 69

Variable stars, 107
Vega, 112
Venerable Bede, 17
Venus, 27, 69
Vernal equinox, 7, 139
Via Lactea, 120
Vibratory theory of substance, 195
Violet light-waves, 73, 91

Weight and mass, 36
Wheel, revolving, 75
Winter solstice, 140
Wollaston, 194

Young, Prof. Charles A., 131
Yule-tide solstice, 8

Zazel, A., ix. 219, 233, 242, 290
Zenith, 5
Zodiac, signs of the, 10, 137